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MANUAL

OF

HUMAN PHYSIOLOGY

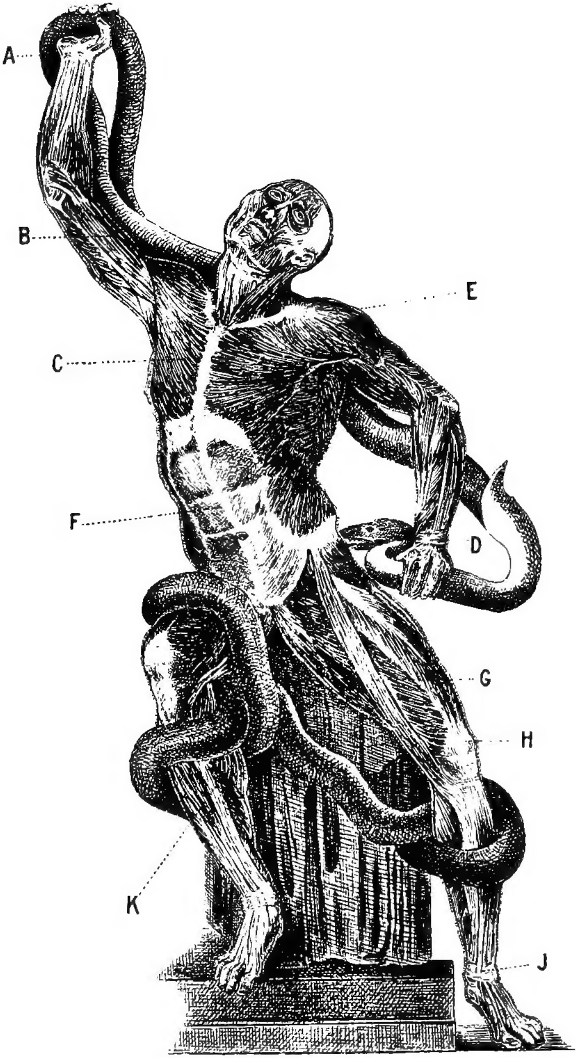

FIGURE TAKEN FROM THE LAOCOON GROUP, and drawn to show the skeletal muscles in action. A, D. Fibrous bands which respectively confine the tendons of the flexor and extensor muscles of the fingers. B. Biceps. C. Pectoral. E. Deltoid muscle. F. Fibrous sheet enclosing muscles of the abdominal wall. G. Sartorius or tailors' muscle. H. Tendon of the great extensor muscles of the leg, attached to the tibia. J. Fibrous band confining the tendons of the muscles which flex the foot and extend the toes. K. The calf-muscles. (After Fau.)

MANUAL

OF

HUMAN PHYSIOLOGY

BY

LEONARD HILL, M.B., F.R.S.

FIFTH IMPRESSION

WITH 177 ILLUSTRATIONS

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'THERE are four impediments to knowledge; first, too great dependence upon authority; second, allowing too great weight to custom; third, the fear of offending the vulgar; fourth, the affectation of concealing ignorance by the display of a specious appearance of knowledge.

ROGER BACON, 1214–1292.

PREFACE

THE author has tried to design this book so as to give the general reader, and one who has not received a scientific education, some insight into the wonderful complexity of structure and function which taken together compose a living man. He has therefore endeavoured to avoid, as far as possible, the use of technical terms, and has sought to lead the student to train himself by observation, dissection, and the performance of simple experiments. It is of no educational value to learn lists of the bones and strings of technical names. To train the power of accurate observation, to develop the imagination and widen the horizon of thought, to increase the manual dexterity of his pupil should be the aim of every teacher. From his experience as an examiner the author has become aware how frequently the students of elementary physiology learn by rote, and not by observation and experiment. Physiology is a subject which cannot be learnt from a text-book alone, and the private student who fails to carry out the simple, practical work described in these pages will prove himself to be but a half-hearted labourer in the field of knowledge. The teacher of a class should illustrate his lessons by the demonstration of the experiments herein described, and should above all provide his students with the use of a microscope.

The author has endeavoured to lay stress on such facts as are of real human interest, and to exclude all unimportant details which interfere with a broad view of his subject. The preliminary chapters, and a few others scattered through the volume, are designed to give the reader some idea of the chemical and physical facts necessary for the understanding of physiology. To condense the requisite knowledge of these facts in an interesting manner is an exceedingly difficult task, and should the reader wish to widen his knowledge he may in addition turn to some elementary text-books on those subjects [1].

As a text-book this volume may be found suitable for students training to qualify as teachers; for nurses undergoing hospital training; for the higher classes of schools and polytechnics. The medical student will find it of some value as an introduction to the more advanced study of physiology. A student who has mastered this book should be able to pass the examinations at South Kensington, both elementary and advanced, and the University Local Examinations.

OSBORNE HOUSE, LOUGHTON, ESSEX,
January 27, 1907.

[1] Perkin and Lean's *Introduction to Chemistry and Physics* will serve the reader most admirably.

CONTENTS

PLATES

INTRODUCTION

In the evolution of man through past ages, from the primitive savage upward, we can trace the progress of knowledge from the vague and the fanciful to accurate and definite views of nature. To the savage, every manifestation or every outbreak of nature's power is waywardness, and fearful in its mystery. By him are storms, fire, winds, and waves personified as gods and demons which control his destiny. By prayers and intercessions he imagines he can alter the career of these powers and thus change his fate. It is only slowly during the course of generations that effects become referred to certain fixed causes. The fisherman learns the signs of the heavens, and puts to sea or seeks refuge according as he views these signs in the light of experience, an experience which is not only personal, but which is handed down by tradition from generation to generation. By experience, the husbandman finds that if he digs the ground at a certain season and plants a certain seed, and waters it when the land is parched, he will reap a harvest at the end of months of patient toil and waiting, a harvest which will supply him with

food when winter rules the land. The huntsman observes that a certain kind of game is to be found in some definite place at some particular season of the year, or when the vegetation bears certain characteristic features. He marks the traces left in the mud leading to drinking pools, and learns to distinguish the footprints of the tiger from those of the deer. So soon as this careful study of any one class of facts arises, there comes about a subdivision of natural knowledge, a subdivision which has so multiplied, until in these days of high civilization the student is confronted with a formidable array of sciences. Each science is built up of the experiences or experiments of generations of men, experiences which have now become so multitudinous that to know any one branch thoroughly is the work of a life-time. But out of this overpowering mass of experiences there can be crystallised simple truths or laws which show to us that, in and throughout nature, certain *causes* are inevitably and invariably followed by certain *effects*. On the knowledge of these laws there is built up the whole fabric of the life of the civilized man, and to know the fundamental facts concerning these laws is not beyond the strength of any man. At the same time this knowledge is of the utmost necessity in order that he may walk, not only with prosperity, but with sanity and health through the stress of life.

Imagine a school-boy cast upon a desert island. In a moment he is bereft of almost all the props of civilization. An hour ago he stood, perhaps, on the deck of a mighty steamer, one appointed with every luxury, ruled in its several departments by

men who for years have laboured at gaining experience; experience of navigation, of steam, of food, and of a hundred other things; acquainted with the signs of the heavens and the laws of nature, sure that certain effects follow certain causes. Can the boy live? It will depend upon the crumbs of experience that he has picked up. Food may lie plentifully around him, but does he know the poisonous from the edible? He may die of cold when fire could be obtained had he but the knowledge and skill of the savage. His island may be separated from the mainland by a strip of sea. This strip, when the tide is low and the wind blows in a certain direction, may perhaps be fordable. Thus he might escape if he waited with the knowledge that the level of the sea alters with the winds and the tides. Such an experience as this would, in a moment, show us how one life depends upon the skill of others. Every day the baker brings us bread, the butcher provides meat, the engineer whisks us to and fro in his train. In civilized communities the function of each man is specialised to one narrow department; for the rest he depends on his fellows.

Imagine yourself turned adrift in London, the sole survivor in a vast depopulated city. Cattle are there, but you know not how to kill or how to prepare meat for food; flour and water are there, but can you bake? Engines rust in station-yards, but you cannot fire or control their energy. Even behind these simple experiences there are a thousand needful trades about which we stand ignorant and helpless. Thus the grass must be grown, the cattle must be reared and fed for the market; the corn sown and

reaped and ground to flour; iron dug and worked, and engines invented and fashioned. About the details it is indeed essential that we should be ignorant, for in a life-time who could master them all, and by specialisation progress is attained.

> . . . 'Each of the many helps to recruit
> The life of the race by a general plan.'

In the specialisation, which comes as the life's task to each one, thoroughness and skill should be the aim, but at the same time, to gain a broad view of the world, and to be assured of the primal concerns of life, it is needful that we should grasp the truths on which all knowledge is based. Surrounded as we are by the scientific wonders of the nineteenth century built up through ages by the labours of generations of men groping in the dark until the light has burst forth in our time, we must remember, that if much has been attained, there is still infinitely more for the goal of our ambition.

> 'Think thou and act; to-morrow thou shalt die.
> Outstretched in the sun's warmth upon the shore,
> Thou say'st: "Man's measured path is all gone o'er:
> Up all his years, steeply, with strain and sigh,
> Man clomb until he touched the truth; and I,
> Even I, am he whom it was destined for."
> How should this be? Art thou then so much more
> Than they who sowed, that thou shouldst reap thereby?
>
> Nay, come up hither. From this wave-washed mound
> Unto the furthest flood-brim look with me;
> Then reach on with thy thought till it be drowned.
> Miles and miles distant though the last line be,
> And though thy soul sail leagues and leagues beyond,—
> Still, leagues beyond those leagues, there is more sea.'

A MANUAL OF PHYSIOLOGY

CHAPTER I

MATTER, MEASUREMENT OF WEIGHT, VOLUME, AND DENSITY [1].

Matter and energy. To each one of us it is evident that he stands as a tiny unit or ego, the world within surrounded by a mighty universe—the world without. In ourselves we recognise a body, the corporeal matter; at the same time we know that this body is endowed with *energy* or *power to do work.* Our hand is built of flesh and bone; the energy of life vivifies that hand, and turns it to cunning use. In the world without we recognise, by our senses, matter and energy. We feel with our hands and see with our eyes that the world is full of substance. In and through this matter, energy, in the form of weight, light, sound, heat, electricity, is constantly manifest. We do not know matter apart from energy. On the other hand, it is conceivable that energy exists apart from matter. Neither energy nor matter are evident to us in all their forms. Thus we cannot see the air, nor smell nor taste it, neither can we weigh it in the hand, but as wind we can feel it when it blows against us. Similarly, when a reed

[1] The first six chapters of this book contain much that is difficult and not very interesting to the beginner. He should take these chapters slowly and meanwhile read onwards from Chap. VII.

of a certain whistle, known as Galton's whistle, vibrates a thousand times a second, it is audible to us as a sound, but it may be no longer audible to us, although it is to the ear of a cat, if it be made to vibrate at a rate exceeding forty thousand times a second.

So, too, when sunlight is split by a prism into its constituent colours, there are rays beyond the violet invisible to us but powerful to produce chemical change in the sensitive plate of the photographer.

Physics and *Chemistry* deal with certain properties of matter and energy and the changes which they undergo. *Biology*, the study of living matter, includes *Morphology*, which deals with the structure and forms of living matter, and *Physiology*, which deals with the functions of life, or rather with the energy which is manifested in living matter.

We meet with the same kinds of energy in the living as in the dead world; living bodies continually take up lifeless substance as food and compound it into living substance, while as constantly they cast forth excreta or waste substances which have become dead. Thus living matter depends for its existence on lifeless matter, and the study of life is bound up with, and forms part of the general study of matter and energy. Physiology is indeed the study of the physics and chemistry of living matter, and this being the case it is necessary that we should, in proceeding with the study of life, learn thoroughly some of the simple and essential facts concerning matter and energy.

By means of trial or *experiment* we study and compare the nature of different forms of matter, and the effect of different kinds of energy on matter. If matter or energy be more or less hidden from us, we contrive methods to make their presence evident or proven to our senses, and especially to our highest sense, that of sight. Thus, although we cannot see the substance of the air, yet we can see that in the air an animal will live and wood will burn; while in another kind of gas, such as that which

rises from a brewer's fermenting-vat, neither can an animal live nor wood burn. Similarly, if we rub a stick of sealing-wax with a silk handkerchief we see no difference in it. Nevertheless, if we bring the sealing-wax near some little scraps of paper, they will be attracted by a kind of energy which has arisen in the sealing-wax owing to the friction. This energy we term electricity.

Comparing different substances which lie around us, we measure with our eyes their size or *volume*, that is, the space they occupy. We hold them in our hands and estimate their *weight*, that is, the attraction or force of gravity which the earth exerts upon them. Comparing the volume of equal weights of various substances, we conclude whether their structure be dense or loose; for example, a pound of cork occupies a large space compared with that of a pound of lead. With our eyes we compare the colour and form of substances, and with our hands we estimate whether they be hot or cold. These are the rough methods of common observation.

Standard of measurement. In order to make exact and uniform comparisons, man has established standards by which all substances are measured, and has invented instruments of precision, such as the balance, the measure-glass, the thermometer, the microscope, &c., by which the weight, the volume, the heat, the minute structure, &c., of any substance can be accurately observed. The use of the balance and the exact measurement of substances submitted to chemical change led to all the great discoveries of modern chemistry.

These instruments are of the utmost importance in the study of physiology.

For all scientific purposes the use of the metric French standards is to be preferred to that of our English system, and England lags behind the European countries in not accepting this system for all purposes of trade.

B 2

TABLE OF METRIC WEIGHTS AND MEASURES.

Measures of length.

1 metre = 10 decimetres = 100 centimetres = 1000 millimetres.[1]

Measures of capacity.

1 cubic metre = 1000 litres = 1,000,000 cubic centimetres = 1,000,000,000 cubic millimetres.

Measures of weight.

1 kilogramme = 1000 grammes = 100,000 centigrammes = 1,000,000 milligrammes.

IN COMPARISON WITH ENGLISH MEASURE.

1 metre = 39 inchès (approximately) about the width of a door. 1000 metres = 1 kilometre can be covered in ten minutes, quickly walking.

25 millimetres = 1 inch (almost).

A half-penny is one inch in diameter.

A penny is about three centimetres in diameter. The finger nail is about one centimetre broad. The width of a man's hand is about one decimetre.

The diameter of an ordinary pin's head is about one and a half millimetres. A sixpence is one millimetre thick.

1 litre = $1\frac{3}{4}$ pint (approximately), a tumbler holds about $\frac{1}{4}$ litre.

1 kilogramme = $2\frac{1}{5}$ lbs. (approximately).

1 gramme = $15\frac{1}{2}$ grains (approximately).

Three pennies weigh about one ounce.

A new French centime (bronze) weighs one gramme.

A French ten centime (bronze) weighs ten grammes.

One fluid ounce of water weighs one ounce (avoirdupois) and it contains about $28\frac{1}{2}$ cubic centimetres and weighs about $28\frac{1}{2}$ grammes.

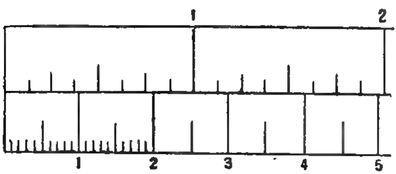


FIG. 1. A scale of two inches compared with one of five centimetres. Two of the centimetres are divided into millimetres. 100 centimetres = 1 metre.

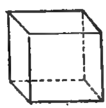


FIG. 2. A cubic centimetre and a square millimetre.

The metric measures increase and diminish by tens, thus they are convenient to use. The standard weight, one gramme, is the weight of one cubic centimetre of water, strictly speaking measured at 4° C., at the maximum density of water, which is the standard volume, while the

[1] Metron (Greek), a measure; decem (Latin), ten; centum (Latin), hundred; mille (Latin), thousand.

height, length, or breadth of the cubic centimetre of water is one centimetre, and that is the standard of length. Thus in the metric system the measures of length, volume, and weight are directly connected with each other. The value of this is seen at once, when you wish to make solutions of a certain strength.

To make a one per cent. solution of common salt, weigh out one gramme of salt, put it in a measure-glass, and add water up to the 100 cubic centimetre mark, and the required solution is obtained.

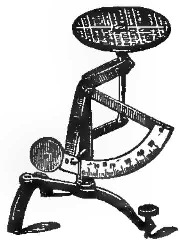


FIG. 3. Balance to weigh up to 50 grms. Made by Gallenkamp & Co. 1*s*.

Weight and volume. Weight is our best means of comparison since *weight* is not altered by temperature, while *volume* is.

A pint of hot water, if allowed to cool, will shrink in volume and becomes less than a pint, but the weight of the water will not alter.

Carry out the following experiments :—

1. Obtain a metre measure-rule divided into millimetres, and with that measure your own height, width of hand, length of foot, &c.

2. Find how many millimetres there are in one inch. Trace the largest square possible on your finger nail. This in area will equal about one square centimetre.

3. Out of soap cut out a cubic centimetre, each side measuring one square centimetre. Buy a graduated measure-glass containing 100 cubic centimetres. Find how many cubic centimetres of water there are in a pint. A small thimble holds about one cubic centimetre.

4. Obtain a set of gramme weights. By means of an ordinary letter-balance find out how many grammes it takes to balance an ounce[1]. For exact scientific work far more delicate balances are used, by means of which the weight of any substance can be determined to the thousandth part of a gramme.

5. Weigh the empty measure-glass. Place exactly 50 cubic centimetres of hot water within it. (To read the volume of water correctly place your eye on the same level as the top of the water. The top of the water has a curved surface—the

[1] Salter and Co's. Letter Balance, No. 11, will carry 1000 grams. 5*s*. 6*d*.

meniscus. The lowest point of the meniscus should be on the mark.) Weigh the glass and the water within it, and determine the weight of the water by subtracting the weight of the glass. Float the measure-glass in a basin of water containing some broken ice. When the water in the glass has become cold, observe that its volume has decreased. Its weight you will find has not changed.

6. Make (1) a $6\frac{1}{2}$ per mille., (2) a ten per cent. solution of common salt and keep these by you in bottles.

For (1) Weigh out $6\frac{1}{2}$ grammes of salt, place it in the measure-glass, and add water up to 100 cubic centimetres. When dissolved add 900 cubic centimetres more of water.

For (2) Weigh out 10 grammes of salt, place it in measure-glass and add water to the 100 cubic centimetre mark.

Density. An inch of cork is much lighter than an inch of lead. A pint of milk is heavier than a pint of water. The weight of one cubic centimetre of water is taken as the standard of density. The density of any liquid can be determined by weighing a measured volume of the liquid and comparing the weight with that of the same volume of water.

A float will sink deeper in a light fluid than in one that is heavy. In comparing densities advantage is taken of this fact.

Take a long wooden penholder and float it in the measure-glass full of water. Mark the level of the water on the stem. The float will sink less in urine or milk because the density of these fluids is greater than that of water.

A glass instrument is sold called the hydrometer, which is made on this principle with the stem graduated. It is used to accurately determine the density of milk, blood, urine, &c., for density gives us indications as to whether the heavier substances in solution are dissolved in a greater or lesser amount of water.

Relative densities of some common liquids :—

Ether, ·73.	Alcohol, ·8.	Turpentine, ·89.
Olive oil, ·91.	Water, 1·00.	Milk, 1·03.
Sea water, 1·026.	Glycerine, 1·26.	Chloroform, 1·47.
Mercury, 13·59.		

An accurate way of determining the density of a solid is to drop small fragments into glasses filled with a number of fluids of different and known density. If the fragment remain suspended, neither sinking nor floating in any one of the fluids, its density is the same as that fluid.

Mix a number of tumblers of sugar and water, place one, two, three, or four, &c., lumps of sugar and the same quantity of water respectively in each.

Take small shreds of raw steak and drop a fragment into each glass. With a hydrometer, determine the density of the solution in which the fragment neither sinks nor floats, but is suspended. You have thus determined the density of flesh or muscle. Repeat the experiment with fragments of bone. Bone is denser than muscle. Tie a string round your finger to congest it, and prick it with a clean needle just behind the nail. A drop of blood will exude. With the head of the needle lift up successive droplets of blood and place one in each glass and so determine the fluid in which the blood neither sinks nor floats. You can thus ascertain by how much your blood is heavier than water. If the density of water be called 1000 on the scale, then that of urine is about 1020, blood, 1060, milk, 1030.

FIG. 4. Hydrometer for determining the density of fluids.

To find the volume of say a bone or a dead mouse. Take a lamp chimney and put a cork in one end to fit tightly. Bore a hole through the cork and pass a glass tube through it as in Fig. 4 *a*. Fill the chimney with water up to the level of this tube, and put a tumbler below to catch the water. Then gently sink the bone under the water. The water displaced by it will run down the tube into the tumbler. Measure the volume of this water.

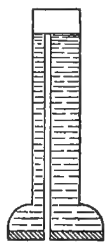


FIG. 4 *a*.

CHAPTER II

ENERGY. THE MEASUREMENT OF HEAT

Energy. Most of us are accustomed in our daily life to view without wonder and accept without curiosity the common manifestations of energy in the world around us. On suddenly turning to the study of natural science we have to cast aside, and not without difficulty, this garment of familiarity with which we have hitherto clothed our ignorance. Not only must we study the world without and ourselves within from an entirely new standpoint, but we must accustom ourselves to clothe in a new language and train ourselves to think in a new way of common things. The idea expressed in the scientific word Energy is one which not only the young student but all of us find especially difficult to grasp. Pull up the weight of an eight-day clock, the weight possesses a store of power, —power to do work. It slowly falls to the ground and drives the clock. The weight is said to possess *potential energy*. Any body possessing potential energy is in a condition of *stress*; it strives to give up its store of energy, just as the weight of the clock strives to run down to the ground. A bent bow strives to become unbent, a charge of gunpowder strives to explode. *Work* must be done to give the weight, the bow, or the gunpowder potential

energy and place it in a condition of stress. An arrow sped from the bow, a weight dropped from the hand, a bullet fired from a gun, have, in virtue of their motion, power of doing work : each possesses *kinetic energy.*

The kinetic energy which a substance acquires when relieved from the condition of stress is equal to the potential energy with which it was endowed. When a weight strikes the ground the kinetic energy appears to vanish, but it is converted into other kinds of energy such as heat, sound, &c., and man has ascertained that the sum total of these energies equals the original potential energy of the weight. Energy is not destroyed, but ends in becoming dissipated as heat.

Every time you idly fling a stone into the air or strike the ground with a stick, the energy of your body is dissipated, and eventually goes to increase the general warmth of the universe.

Rub a knife upon a stone. The knife becomes hot. Twist a piece of stout wire backwards and forwards to break it. The wire may become too hot to hold. Energy of movement can be converted into energy of heat.

Strike a flint with a hammer. Sound is produced, sparks fly and the hammer becomes warm. Energy of movement is convertible not only into heat, but into light and sound.

The weight of a flat-iron is not altered when it is heated, yet its energy or power of doing work is thereby increased. In the evenings of summer days, the occupants of an old manor house were disturbed by the sound of a sudden rush and clatter as it were of many ghostly feet passing along a gallery which lay beneath the roof. The mystery for years remained unexplained until the roof was one day repaired. It was then found that a long leaden gutter lying above the gallery had no room to expand in length when heated by the summer sun. It thus became raised by the energy of the sun's heat, only to fall down with a clatter in the evening when it once more cooled and contracted.

The measurement of heat. Substances expand on heating. Noting this fact, man has learnt to measure the temperature of the things about him by observing the expansion of mercury, a substance elected to be the most suitable.

(1) Make a loop of wire which will just allow the poker to slip through ; heat the poker in the fire : it cannot slip through the loop any longer. The heat of the fire passes to the poker and expands it. Put the hot poker into a pot of water, the poker cools and the water becomes warmer. Heat passes from a body at a higher *temperature* to that at a lower temperature until both are at the same temperature.

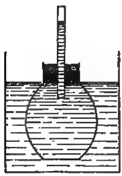


FIG. 5.

(2) To show that water expands when heated. Take a bottle with a tight-fitting cork. Make a hole through the cork and insert a piece of glass tubing. Fill the bottle with water: put in the cork : the water rises a little way up the tube. Now put the bottle into a bath of hot water. The water in the bottle expands and rises up the tube.

The Thermometer consists of a small bulb placed at the end of a straight glass tube. The bulb is filled with mercury. When heated, the mercury, as it expands much more than the glass, rises up the tube. So soon as the tube is full, the opening at the top is sealed in a flame. The mercury when cold shrinks down the tube again. The melting point of ice and the boiling point of water are determined by placing the bulb first in iced water, and then in the steam of boiling water. In each case the level of the mercury is marked on the tube or on a scale placed behind the tube. Between these marks, and above and below them, the scale is divided into a number of equal lengths or *degrees*. In the Centigrade scale, the melting point of ice is called 0° C., and the boiling point of water 100° C. There are 100 degrees marked off between these points.

In the Fahrenheit scale, which is not so convenient, but is commonly used in England, the melting point of ice is called 32° F., and the boiling point 212° F. To convert degrees Fahrenheit into degrees Centigrade it is necessary first to subtract 32 and then to multiply by 5 and divide by 9.

Thus 50° F. = 10° C., for $50-32=18$ and $18\times\frac{5}{9}=10$.

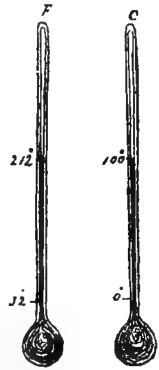


FIG. 5*a*. Fahrenheit and Centigrade thermometers showing zero and boiling points.

Buy a cheap thermometer scaled up to boiling point, viz. 212° F.

Obtain some ice from the fishmonger. Place the mercury bulb in melting ice and, on the opposite side to the Fahrenheit scale, mark the level of the mercury as 0° C. Now place the bulb in water kept boiling, and observe the expansion of the mercury; when it has ceased, mark the level of the mercury as 100° C. Measure the distance between 0° and 100° and divide it into ten equal parts. Divide each of these parts again into ten. You have thus made a Centigrade scale. Compare this with the Fahrenheit.

Hold the bulb of the thermometer tightly under your armpit. The warmth of the body remains constantly at about 98·5° F., or 36·9° C.

As the tongue tastes the salt in the sea, but cannot tell how much salt there is in a gallon of sea-water, so the thermometer measures the *intensity* not the quantity *of the heat.* We can place it in a bath and find out how hot is the water, but the thermometer does not tell us how great is *the quantity of heat* in the water. When a teacupful of tea is just poured out it is of the same temperature or as hot as the tea in the teapot, but owing to its smaller size it contains a smaller quantity of heat and so becomes cold sooner than the tea in the teapot.

Quantity of heat is determined by another instrument, *the calorimeter.* This consists of a thin copper pot containing a measured weight of cold water, say 200 grammes (about seven ounces), and provided with a stirrer and a thermometer. Suppose you want to determine the quantity of heat in an egg weighing say 56 grammes (about two ounces), and boiling hot, you can proceed as follows. Take the temperature of the water in the calorimeter and note it, drop in the egg and leave it till the water has cooled the egg and the egg has heated the water, and both have become of the same temperature; then take the temperature of the water again. From the change that the temperature of the water has undergone, you can determine how great a quantity of heat the 56 grammes of egg has imparted to the 200 grammes of water.

During the experiment the water must be constantly stirred in order to equally diffuse its heat (since hot water rises to the top and cold sinks to the bottom), and the copper pot must be surrounded with a jacket of cotton-wool, or of felt, to prevent it losing heat. Just as we measure the weight of a substance with a balance, so with the calorimeter we can measure the quantity of heat it contains. While the standard measure of weight is one gramme (the weight of one cubic centimetre of water at 4° C.), the standard measure of quantity of heat is the heat required to raise one gramme of water through one degree centigrade. This standard measure is termed a *calorie.*

The capacity for heat, that is to say, the amount any substance will take up, varies very greatly. Thus, if 50 grammes of brass and 50 grammes of potato be together boiled in water until they both have reached the temperature of 100° C., these two bodies will be found by the calorimeter to contain different amounts of heat. The amount can be determined by dropping each separately, when at 100° C.,

into a calorimeter, and by then measuring by how much each substance respectively heats the measured weight of water contained in the calorimeter. By such means we learn the capacity for heat possessed by different bodies. A bottle full of mercury would, when placed over a fire, reach a temperature of 100° C. much sooner than a bottle full of water, for the heat capacity of mercury is much less than that of water. A cold-blooded frog, or an egg with a live chick inside, takes about the same quantity of heat to raise them through one degree, as does an equal weight of water. Man, in common with all hot-blooded animals, cannot be heated or cooled, except within very small limits, without destruction of life. He possesses an extraordinary mechanism of which you will learn later, and by means of this, he can lose heat as fast as it is gained; thus, by constantly regulating the internal temperature of his body, man can live either in the tropics or the arctic regions. The body of a man, like a fire, is constantly burning and producing heat; he is fed with food in place of fuel. If a man be shut up inside a large copper calorimeter full of air, surrounded on the outside with wool or felt, and some ice be placed inside with the man, the amount of heat he produces per hour can be measured by observing how much ice is melted in that time.

Obtain a bright tin pot, a cocoa-tin will do. Surround the pot with a sheet of cotton-wool. This will do for a calorimeter. (1) Place 50 grms. of water in the pot. Take the temperature of this. Boil a 50 grm. brass weight in water. Lift it out with a spoon, drain off any water, and quickly drop it into the calorimeter. Stir with the thermometer and read the highest temperature attained. Calculate how many calories each grm. of brass contained. Repeat with an egg weighing about 50 grms. (2) Place a lump of ice at the bottom of the tin, and placing two fingers within, surround the orifice with cotton-wool. After five minutes quickly remove the ice which has not melted with a spoon, and measure the amount of water in the pot. From

this, you can calculate roughly how much heat your two fingers have given off in five minutes, for it takes 80 calories of heat to melt one gramme of ice into water. The heat given off by the whole body of a man is determined on the same plan.

Conduction, convection, and radiation. A dry hot body loses its heat in three ways. Firstly, by *conduction* to matter with which it comes in contact. Thus you give up heat to whatever your body touches. Some substances conduct heat better than others.

Place a silver and an iron spoon in the same hot water; the silver spoon conducts heat more rapidly, and will, before the iron spoon, become hot to the hand.

Secondly, by *convection*. As the air in contact with the body grows hot it expands, and, becoming lighter, is driven up by cold air which descends owing to its greater weight. Thus a continual current of air is set up to and from any substance which is warmer than the air.

A feather, thistle-down, or wisp of wool, is carried up by the warm current of air that rises from a lamp.

Thirdly, heat may be lost by *radiation*. Radiant heat passes in all directions from the body, in the same way as heat radiates from the sun to the earth.

A piece of woollen cloth conducts heat badly. Air is a very bad conductor of heat. Thus kettle-holders are made of cloth, and we enclose a teapot in a cosy and ourselves in clothes, because it entangles air in its meshes and prevents loss of heat by convection. The still air does not conduct. Polished surfaces are good reflectors, and so reflect back radiant heat. Thus dish-covers are made bright and polished that they may retain the heat.

A moist body loses heat not only by conduction, convection, and radiation, but also by the evaporation of water.

CHAPTER III

GAS, LIQUID, AND SOLID.

You are familiar with the fact that water, *liquid* water, disappears as *vapour* or *gas* when heated, and turns into hard, *solid* ice when frozen. Similarly steam becomes water when cooled, and ice turns to water when heated. It is clear enough that water undergoes a *change of state* under the influence of heat. Heat is one kind of energy. In consequence of lessened heat, water, when it freezes, may burst iron pipes, for it is a peculiar characteristic of water that it expands when cooled below 4° C. As a result of increased heat, water likewise expands, and may burst an iron boiler, that is to say if the boiler be not supplied with a safety-valve. Water occupies the smallest space when at a temperature of 4° C. Ice forms at the top of ponds because the water, cooled to 0° C., is lighter than water at 4° C. The ice protects the water below from cooling by wind. It is owing to this fact that the living things in the water are not frozen up and destroyed.

On looking about us, we find substances are familiar to us as solids, as liquids, and as gases. Many of these substances undergo a similar change of state when cooled or heated, but some require far greater changes of temperature to effect any alteration in their state. Thus you may not be aware of the existence of such substances otherwise than in the familiar state.

You know that iron can by enormous heat be turned into a molten liquid mass.

You probably do not know that mercury, the silvery liquid which you see in thermometers, may freeze into a solid metal under the intense cold of an arctic winter, and that when frozen to a solid it may be hammered like a piece of lead. On the other hand, by a high degree of heat, mercury may be rapidly turned into a vapour or gas.

It is a far more astonishing fact that the air which we breathe can by enormous cold and pressure be turned into a liquid, and even into a solid white as snow. Thus a bottle of London air has been carried as liquid air to Oxford, and there set free again as gaseous air.

It is clear then that a substance can exist in three states, gas, liquid, or solid, and yet be in all these states one and the same substance.

Melt some powdered sulphur in a test-tube over a Bunsen flame or a spirit-lamp. It turns into a yellow liquid, which thickens and becomes dark red, then it thins again and begins to boil. On cooling it solidifies into a solid cake of sulphur. Heat a few pieces of tin, or lead, in an iron spoon and pour the melt (*a little at a time*) into a pot of water.

Find the melting point of paraffin or butter. Take an inch of glass tubing: stop up one end by holding it in a Bunsen flame at an angle of 60° till the glass melts and closes the opening. Put a little wax off a candle, or butter, in the tube and attach it to the bulb of a thermometer by a rubber band. Immerse in water, and warm the water, stirring all the time, till the stuff melts. Note the temperature at which this happens.

Some melting points:

Gold, 1062° C.	Common salt, 851° C.	Lead, 326° C.
Tin, 233° C.	Sulphur, 115° C.	Paraffin, about 54° C.
Butter, 33° C.	Ice, 0° C.	Mercury, −39° C.

Place a few crystals of iodine in a test-tube and cautiously warm, holding the tube almost horizontal. Some of the iodine melts, but heavy violet vapour is also given off. This deposits on the upper cool parts of the tube as crystals of iodine.

Now in the study of life we shall be continually talking of gases, liquids, and solids, we breathe air (gas), we drink liquids, and we eat solids. It is necessary to know roughly the differences between these three conditions which any kind of matter may assume under the influence of heat.

Gas. A gas is not sticky to feel, nor tough, nor hard, you cannot stretch or bend or twist it with your hands.

A gas occupies any space in which it be confined; if the space be diminished the gas becomes compressed, i.e. smaller in volume; if enlarged, the gas expands to fill it.

1. Take a well-made bicycle pump, stop up the nozzle with the finger and press the piston. To drive in the piston you must exert more and more pressure; with the finger on the nozzle you feel the pressure becoming greater and greater. Let go the piston, it immediately flies back again to its former position. By this experiment you learn (1) that the volume of the air in the pump becomes smaller as the pressure becomes greater; (2) the pressure of the air becomes greater as the volume of the air becomes less; (3) the air is *perfectly elastic*, that is to say, it recovers its original volume when the pressure is removed.

2. Take a piece of glass tube about 10 inches in length. Suck a little water into one end of the tube. Slip over the other end an inch of rubber tubing, and stop up the end of this with a piece of pencil, then warm the air in the tube over a gas flame. The water will be gradually driven out as the air becomes hotter and hotter. To stop the water from moving, pressure must be exerted, and the pressure must be greater as the air becomes hotter. This shows you (1) that air expands when heated; (2) that air presses if it be not allowed to expand when heated. It has been determined that all gases when equally heated expand to a like extent or exert pressure to a like amount.

3. Warm a penny air-balloon before a fire, the air will expand and press upon every part of the walls of the balloon until the balloon bursts. If you press an air-balloon at any part, the air will *flow* from the point of greater pressure to all points of less pressure. Thus the bag becomes distended elsewhere, and the pressure equalised throughout the balloon. A gas enclosed in any shaped vessel presses equally on every point of the walls of that vessel.

Solid. In contrast with a gas, a solid, such as a penny, has a definite form or shape and resists your efforts to deform it. A solid does not expand to fill or flow or fit any space in which it may be enclosed, and it is very

difficult to compress it even to the smallest extent so as to make it occupy a smaller space. If you make a wire ring through which a penny can just pass, and then heat the penny by holding it in the gas with a pair of tongs, you will find the penny has slightly expanded, and will not pass through the wire ring. Solids expand a very little on heating, and shrink again on cooling. When expanding, they exert great pressure, and when shrinking, great tension or pulling force.

Liquid. Liquids can flow and thus fit themselves to the shape of any vessel. A liquid, for example treacle, unlike a gas, takes time to do this. A small quantity of liquid enclosed in a bottle does not expand like a gas to occupy the whole bottle. Particles of liquid do not cohere or stick together with anything like the tenacity of a solid. Thus any part of a liquid can slip or flow past any other part.

Substances such as putty, wax, or honey lie on the borderland between liquids and solids. Putty or wax, when warmed, can be deformed and made to take the shape of any vessel. Even lead is plastic and can be moulded by force into shapes, iron is ductile and can be drawn out into wire. At Woolwich Arsenal large pieces of cold brass are forced into the shape of shells by powerful machines. Liquids expand slightly with heat, and contract with cold. In the case of liquids and solids, different substances expand when equally heated to different amounts. In the case of gases, the expansion is the same for all.

Molecular structure of matter. Since all pieces of matter can be contracted by cold into a smaller, and expanded by heat into a larger space, man is led to imagine that each substance consists of small particles separated from each other by space. Take a lump of chalk, powder it down finer and finer until it appears to the eye to be formed of fine dust. You can still continue to grind it, until each particle is perhaps a thou-

sand times smaller, and appears under the high power of the microscope as the finest dust. Imagine dividing and dividing the chalk still further, until a point is reached where it can no longer be divided without change of nature. The ultimate particles of such a division would be infinitely too small to be seen. Suppose a drop of water could be magnified to the size of the earth, then perhaps we might see the ultimate particles of water as the size of footballs. Chemists and physicists have very good reason to believe that all matter is formed of ultimate particles, or *molecules*, as they are called. If we once boldly accept this hypothesis, many things can be explained in a very simple way.

It is believed that heat makes the molecules move to and fro. In the case of a solid, the molecules are packed so tightly that they cannot move past, but only oscillate about each other.

A solid may be likened to a densely packed crowd of men forming a solid mass round a theatre door. Within the crowd, each molecule moves only slightly to and fro, for not only is it attracted to its neighbours, but it is jostled and impeded on all sides by other molecules. On the outside of the crowd the molecules may very slowly become disentangled and move away and leave the mass. Thus, a solid piece of camphor gradually vapourises away. When a solid is heated the molecules dance to and fro with greater and greater vigour, and the crowd expands and becomes less dense. Finally the solid fuses or liquefies. It requires a great quantity of heat to change ice into water, because the heat is expended, or rather becomes hidden or latent, in increasing the movement of the molecules. Energy has to be absorbed in order that the work of tearing the solid into liquid may be done. Similarly it requires a prolonged frost to freeze a deep pond. By continually withdrawing the latent heat of the water, the movement of the molecules is slowly lessened until they crowd together and form ice.

A liquid is like a more open crowd, in which the molecules can with less difficulty move about and shift their position. A liquid can be broken far more easily than a solid, just as a loose crowd of men can be broken up by the police far more easily than a dense crowd. The molecules on the outside escape too with greater ease, thus liquids turn into vapour far more quickly than do solids. To turn a liquid into a gas a great quantity of heat is required. It is spent in increasing the movement of the molecules to a still further degree. Thus, sweat, water, or alcohol, evaporating from the hand, will produce a sensation of cold. The body of man is kept cool on a hot day by the evaporation of sweat.

In the case of a gas the molecules form a sparse crowd. When one cubic centimetre of water at 100° C. becomes steam, it occupies a volume nearly eighteen hundred times as great. Each molecule of a gas moves continually with the greatest speed. It flies in straight lines, first in one and then in another direction, as it strikes against and rebounds from its fellow or from the boundary of the space which it occupies.

Each molecule has an attraction for its fellow. Hence the cohesion of a solid, and its resistance to being bent or broken. When heat increases the motion of the molecules, the attraction becomes less, and the molecules move further apart and cohere less closely. In the case of a gas, the attraction of one molecule for another becomes so slight that it is to us insensible.

You can walk through the air, pushing your way through it, without any feeling of resistance. Through the sea, you can cleave your way, parting the waters as you go. But you cannot run as fast through the sea as through the air, for the water resists your passage. Through sand, it is effort enough to push one's feet, you cannot walk *through* a hill of sand.

Latent Heat of Liquefaction. Take two small cocoa-tins: in one place 100 c.c. (cubic centimetres) of cold tap-water; in the other place 50 grammes of ice and 50 c.c. of the same tap-water. Float both tins in a saucepan of boiling water, and with the

thermometer and a watch compare the time it takes to raise the temperature of the water in each tin up to 50° C. This experiment will show you that much heat is required to melt ice.

Note that the temperature does not rise above 0° C. so long as there is any ice unmelted. The melting point is a constant temperature. The latent heat of ice is very high. It requires 80 calories to melt 1 gramme. If it were not for this the mountain snows would rapidly melt and flood the lowlands.

Mix one part of common salt and four parts of snow or pounded ice. This acts as a freezing mixture, i. e. robs surrounding things of heat. This is so because the freezing point of brine is far below that of water (−22° C.).

Heat is given out when a liquid solidifies. Take some crystals of 'hypo' (sodium hyposulphate)—any druggist or photographer has it. Place them in a clean test-tube. Heat gently till melted, Put a plug of cotton wool in mouth of tube and set aside to cool. Remove plug and drop in one little crystal of 'hypo.' The liquid quickly solidifies. Feel the tube, it is quite hot.

Latent Heat of Vapourisation. Place 100 c.c. of water in a flat dish (a tin soap-dish will do), and float it on a pot of water kept at the boil. Measure the time it takes (1) to raise the water in the soap-dish to boiling point, (2) to evaporate it all away. This experiment will show you what a deal of heat is required to convert water into vapour. While the water is turning into vapour it remains at 100° C. This is called the boiling point of water.

Some boiling points: Sulphur, 44° C.; Mercury, 357° C.; Toluene, 110·3° C.; Water, 100° C.; Alcohol 80·4° C.; Chloroform, 60·2° C.; Ether, 35° C.

A substance could be kept at any one of these temperatures by surrounding it in a bath of any one of these liquids and boiling the liquid.

Put a cold plate in front of the jet of steam issuing from the spout of a boiling ketttle. Drops of water *condense* on the cold plate. This is the purest water obtainable. Water is 'distilled' on this principle. Some liquids cannot be distilled, e.g. olive oil, and are called *non-volatile.*

Note how quickly the plate is heated by the steam, the plate is warmed when only a little water has been condensed. This is because of the high value of the latent heat of vapourisation. The latent heat is set free as the steam condenses. To convert 1 gramme of water at 100° C. into steam at 100° C. no less than 537 units of heat (calories) are required, in other words enough heat to warm more than half a litre 1° C.

CHAPTER IV

ELEMENTS AND COMPOUNDS.

THUS far we have learnt that heat may produce a change of state in matter. A substance may become hot or cold, expand or contract, turn into gas, liquid, or solid, and yet undergo no change in weight or nature. There exist about seventy different substances which when pure cannot be altered in any other way by any degree of heat attainable by man. These substances cannot at present be broken into any simpler forms of matter and are termed *elements.* There is some evidence to show that the elements may be broken up by the intense heat in the stars. The evidence is obtained by examination of starlight with an instrument called the spectroscope. Recent discovery has also proved that the element radium gives off an emanation which, some think, changes into another element, helium. Such change is extremely slow, only detected by the most refined electrical methods, and cannot be initiated or controlled by man.

You know the rocks and soil vary in nature in different places. Think of slate, the sand of the shore, chalk, flint, coal, clay, &c. These are the raw materials upon which the alchemists of the middle ages experimented, and from which by the action of fire they prepared many new substances in their crucibles. The modern chemist from coal alone has prepared hundreds of valuable substances, coal-gas, coke, gas lime, tar, the products of tar including many medicines and antiseptics such as carbolic acid, all the beautiful aniline dyes, &c. The raw materials of the earth are *compounds* from which simpler substances can be formed. From these simpler substances finally the elements are separated.

Elements. Iron, lead, gold, silver, copper, aluminium, are examples of metallic elements. These are familiar to you as solids. Mercury, used in thermometers and barometers, is known to you as a liquid metallic element. Sulphur sold

in yellow lumps or powder, and carbon, such as forms the black-lead of pencils, are non-metallic solid elements. Phosphorus is a solid and very inflammable element. It is known in two forms, one yellow and the other red. The element chlorine is a yellowish-green gas, with an irritating smell. Bromine is a deep red liquid element, with a very pungent irritating smell. Iodine is a black crystalline solid, somewhat lustrous like a metal. It can easily be turned into a vapour of a wonderful violet colour.

Sodium, potassium, calcium, and magnesium are metallic elements, but these, like phosphorus, chlorine, bromine, and iodine, are not familiar substances.

The air is composed of a mixture of gaseous elements, oxygen ($\frac{1}{5}$), nitrogen ($\frac{4}{5}$), with traces of other gases.

Oxygen supports combustion. Coal or wood will burn only in the presence of oxygen, and life cannot continue in the absence of this gas.

By the admixture of nitrogen the oxygen of the atmosphere is diluted. By nitrogen neither combustion nor life can be maintained.

Hydrogen is a very light gas. A balloon filled with hydrogen is much lighter than the air, and so ascends. Hydrogen burns in the presence of oxygen. By intense cold and pressure hydrogen gas has recently, like all other gases been converted into a liquid form.

Compounds. Matter is indestructible. It can be compounded into complex bodies or broken down into elements, but can neither be destroyed nor altered in weight. The greater number of the substances that we see around us are not elements, but are compounded of two or more elements. These *compound* substances may be *decomposed* or broken up into elements by heat. To decompose some, but little heat is required, while others are scarcely broken up by the greatest heat attainable. Mix sand and sugar, the particles of each can be detected under the microscope and such adulteration is easily detected. Mix the gases hydrogen and oxygen in a bottle, each gas can still be recognised by certain tests. Let them burn and a new

compound is immediately formed, namely, a drop or two of liquid water. *A compound differs from a mixture.*

Elements, when placed in contact, by different means may be made to combine and form compounds. Compounds too may combine with other compounds and form very complex bodies. As a rule a compound does not resemble in any of its properties the elements of which it is composed.

Atoms. We have already agreed to express by the term *molecule* the smallest particle of any substance which exhibits properties of that substance, and which cannot be split into parts without destroying those properties. Since water is compounded of hydrogen and oxygen we must suppose that each molecule of water is formed by a combination of elementary particles of hydrogen and oxygen.

These elementary particles are called atoms. We think that all molecules are compounded of atoms. Every atom of any one element is believed to be exactly like every other atom. When *any* atoms of hydrogen are taken and compounded in the right proportion with *any* atoms of oxygen, water is always produced. Compounds do not contain haphazard proportions of the elements. It has been conclusively proved that every pure compound like water always contains the same elements in the same definite proportions. If oxygen and hydrogen be mixed in a glass bottle in the proportion *by weight* of 8 to 1, and the mixture be exploded by an electric spark, the whole of the gas disappears, and forms a few drops of water. If more than this proportion of either gas be taken, some of it will remain uncombined after the explosion. Oxygen and hydrogen will combine to form water in the proportion by weight of 8 to 1, and in no other proportion. In every molecule of water the oxygen forms eight parts by weight, and the hydrogen one. Similarly definite proportions of the elements are found to be combined in all other compounds.

Atomic weight. By finding the weights of the different elements which enter into a combination, and by other means which need not concern us here, the comparative

weight of the atom of each element has been determined. Hydrogen, the lightest of all, is called 1; an equal volume of oxygen (measured under the same conditions of pressure and temperature) is 16 times, nitrogen 14 times, mercury vapour 200 times as heavy.

Chemical symbols and equations. Each element is known by a symbol which expresses its atomic weight. These symbols are used in the form of a chemical equation to represent the final change which takes place when elements or compounds react with each other and form new compounds. For example:—

$$H_2 \quad + \quad O \quad = \quad H_2O$$

$$\text{2 parts of hydrogen by weight} + \text{16 parts of oxygen by weight} = \text{18 parts by weight of water.}$$

Table of symbols and atomic weights of some of the elements.

	Element.	*Symbol.*	*Approximate Atomic or combining weight.*
	Barium	Ba	137
	Bromine	Br	80
2 lbs.	*Calcium	Ca	40
21½ lbs.	*Carbon	C	12
4 ozs.	*Chlorine	Cl	35
	Copper	Cu	63
a trace	*Fluorine	F	19
	Gold	Au	196
13½ lbs.	*Hydrogen	H	1
a trace	*Iodine	I	127
$\frac{1}{10}$th oz.	*Iron	Fe	56
12 ozs.	*Magnesium	Mg	24
	Mercury	Hg	200
4½ lbs.	*Nitrogen	N	14
106 lbs.	*Oxygen	O	16
1½ lbs.	*Phosphorus	P	31
1 oz.	*Potassium	K	39
	Silver	Ag	108
3½ ozs.	*Sodium	Na	23
2½ ozs.	*Sulphur	S	32
	Zinc	Zn	65

The elements marked with a star are obtained on decomposing the body. From a man weighing 150 lbs. in about the amounts indicated at the side.

Analysis and synthesis of compounds. If the two wires of an electric battery be dipped into a glass containing

water acidulated with sulphuric acid (vitriol), the flow of electricity through the water will cause the evolution of bubbles of gas around either wire[1]. If the gas which bubbles up from either be collected in glass tubes, it can be proved (1) that oxygen streams from one wire and hydrogen from the other; (2) that the amount of oxygen obtained will be *by weight* eight times as great as the amount of hydrogen, in the form of an equation $H_2O = H_2 + O$. Water is thus split up by *electrolysis* into its component elements, and these elements can be mixed, exploded by a spark, and again made to form water. Many compounds, when in solution or mixed with other compounds, can be split up into elements by electrolysis. The chemist can, in this and in several other ways, decompose compounds, and thus determine or *analyse* elements of which they are compounded. Similarly he can compose or *synthetise* compounds out of elements. Every compound is decomposed if submitted to a high enough temperature, but the elements cannot in all cases be separated and analysed by this means. Example, preparation of oxygen from mercuric oxide.

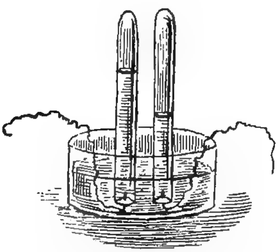


FIG. 6. Decomposition of acidulated water by an electric current. The hydrogen formed is twice the *volume* of the oxygen.

Place some red oxide of mercury at the bottom of a glass tube. Cork the tube. Insert one end of a glass pipe through a hole in the cork. The other end of the pipe must be led under a glass jar filled with water and standing inverted in a basin of water. On heating the red powder by holding the glass tube in a flame, oxygen gas bubbles over into the jar and displaces the water. At the same time, vapour of mercury condenses as beads of liquid mercury on the colder parts of the tube. The change is represented by the equation

$$HgO = Hg + O.$$

The chemist determines the nature of any substance he,

[1] See Chap. V.

has obtained by examining its qualities or testing its behaviour under varying conditions. Each substance is known by certain characteristic *tests*. Thus a match blown out, but still glowing red, will burst into flame if placed in a jar of

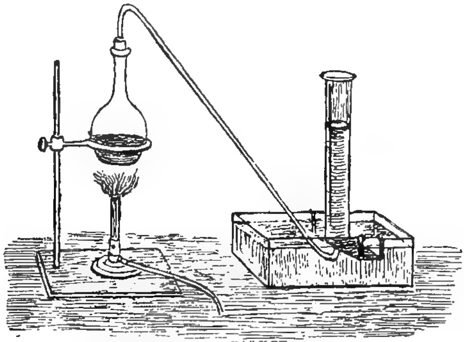


FIG. 7. Production of oxygen by heating red oxide of mercury.

oxygen. Oxygen will not burn but can support combustion. An animal can live in oxygen but cannot in hydrogen.

Hydrogen is inflammable and burns. If mixed with oxygen and set fire to, it explodes and forms water. It is very light, much lighter than air, and if used to fill a paper balloon, will carry it up into the air.

A solution of starch such as boiled arrowroot, turns a deep blue colour when a drop of iodine solution is added to it. The blue colour only appears when the solution of starch is cold, and disappears when it is heated.

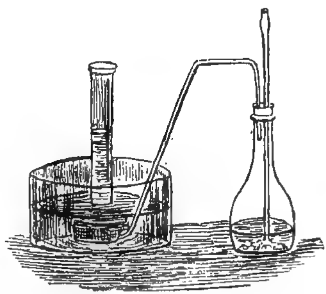


FIG. 8. Production of hydrogen.

Fat melts at a given temperature and dissolves in ether but not in water.

A solution of egg-white—a proteid—coagulates (sets into a jelly) when heated, and turns yellow when heated with nitric acid.

An element may be split off from a compound by *displacement.*

Place some zinc at the bottom of a wide-mouthed bottle. Cork the bottle and insert through the cork (1) a funnel, (2) a glass pipe leading to the gas-collecting jar arranged as in the last experiment. Down the funnel pour some water and then a little hydrochloric acid. *Reaction* will take place between the acid and zinc whereby they become chemically altered. In consequence of this reaction, a stream of hydrogen gas will pass over into the collecting-jar. Hydrochloric acid is compounded of two elements, hydrogen and chlorine. When this acid comes in contact with the zinc, the chlorine combines with the zinc, and the hydrogen is displaced or turned out. At the same time as the hydrogen is displaced, zinc chloride is formed by the *synthesis* of chloride and zinc

$$Zn + 2HCl = H_2 + ZnCl_2.$$

Sodium peroxide can be decomposed, by the mere addition of water, into caustic soda and oxygen. Thus

$$Na_2O_2 + H_2O = 2NaOH + O$$

Peroxide of soda + water = caustic soda + oxygen.

Calcium hydride similarly yields hydrogen

$$CaH_2 + 2H_2O = Ca(OH)_2 + 2H_2$$

Calcium hydride + water = slaked lime + hydrogen.

Many elements unite together and form compounds when brought in contact under certain conditions of heat, light, pressure, &c. Such syntheses are usually accompanied with the liberation of energy, generally in the form of heat. If light, as well as heat, be produced, *combustion* occurs, and the substances burn. When hydrogen unites with oxygen to form water, it burns with a pale blue flame and gives off a great deal of heat. When coal-gas, which is a mixture of compounds containing carbon and hydrogen, burns, the carbon unites with oxygen to form a gas called carbon dioxide, while the hydrogen unites with oxygen to form water.

By heat, complex compounds may often be split into the more simple compounds of which they are composed. Thus, soluble bicarbonate of lime, which occurs in the hard

water of chalky districts, is split by boiling into insoluble carbonate of lime, carbon dioxide and water. The carbon dioxide escapes as a gas, the water evaporates away, and the carbonate of lime is left as *fur* in the kettle.

$$H_2Ca(CO_3)_2 = H_2O + CO_2 + CaCO_3.$$

When two compounds are brought together in solution, there may take place between them an exchange of an element or of a group of elements. Two new compounds are thus formed. If one becomes insoluble it falls down as a *precipitate*, and may easily be separated if the other remain in solution. Likewise, if one of the new compounds become a gas, it will escape, and be separated if the other remain in solution.

Mix a solution of sodium chloride with a solution of silver nitrate (lunar caustic); a heavy white precipitate of silver chloride falls down to the bottom of the glass and sodium nitrate goes into solution.

$$AgNO_3 + NaCl = AgCl + NaNO_3.$$

If the precipitate be shaken up and with the solution be thrown into a funnel of filter-paper (blotting-paper), the precipitate will stay behind on the paper, and can thus be separated, washed, purified, and dried.

The analytical and synthetical methods of the chemist are constantly used by the physiologist in the study of the chemical nature of the body and food of man.

Distribution of important elements. Oxygen forms one-fifth of the volume of the atmosphere, and eight-ninths of the weight of water. Hydrogen forms one-ninth of the weight of water. Nitrogen forms four-fifths of the volume of the atmosphere. The oxygen in the atmosphere is necessary for the existence of life. Water (H_2O) forms two-thirds of the body weight. The elements carbon, hydrogen, oxygen, nitrogen, are compounded together into a very complex substance called *proteid*. Water 80% and proteids 20% form the flesh of a dead man. Sulphur, and sometimes phosphorus, are also combined in the proteid molecule. Sugar ($C_6H_{12}O_6$) and starch ($C_6H_{10}O_5$) are complex bodies, consisting of carbon, hydrogen, and oxygen united in

certain definite proportions. They contain twice as many parts of hydrogen as of oxygen, and are termed *carbohydrates*. The carbohydrates, sugar and starch, are formed by plants out of water and carbon dioxide, under the influence of sunlight and warmth. A kind of sugar called grape-sugar occurs in the blood, and animal starch or glycogen in the liver. Carbohydrates with proteid, fat and mineral salts form the food of man.

The fat of the body is compounded of the elements carbon, hydrogen, and oxygen united in certain proportions. The fat contains more than twice as many parts of hydrogen as of oxygen. When fats and carbohydrates are burnt, they break down into simpler substances, namely, carbon dioxide gas (CO_2) and water vapour (H_2O), while proteids on combustion yield carbon dioxide gas, water vapour, and ammonia gas (NH_3). From the living body of man the waste products, carbon dioxide, water, and urea (CON_2H_4) are continually given off. Urea can be easily broken down into carbon dioxide, water and ammonia.

Acids and salts. The alchemists made all kinds of experiments on the raw materials of the earth, heating them with fire, alone, or mixed with other things, distilling off vapours, &c., and thus discovered many new substances. Among these were substances with strong acid or alkaline taste, acid like lemon juice or alkaline like washing soda. From green vitriol (ferrous sulphate), heated in a retort, they distilled sulphuric acid, or oil of vitriol, a powerful acid which chars paper or sugar, and when mixed with water becomes very hot. By acting on common salt with sulphuric acid they obtained hydrochloric acid or spirit of salts.

$$H_2SO_4 + 2NaCl = Na_2SO_4 + 2HCl.$$

By acting on nitre with sulphuric acid nitric acid (HNO_3) was obtained, an acid which turns the skin or any proteid yellow. Beer or claret left exposed to the air becomes sour. This is owing to the growth of a fungus, which changes the alcohol into acetic acid.

Soda or potash heated with lime yields caustic soda or potash, alkalies which feel soapy, and clean grease off the

hands. By heating sal ammoniac (ammonium chloride) with lime the alchemists obtained ammonia, an alkali with pungent odour. Acids turn a dye, called litmus, red, alkalies turn it blue.

When hydrochloric acid and caustic soda are mixed common salt is formed and water.

$$HCl + NaOH = NaCl + H_2O.$$

A salt can crystallise, is saline to taste, neutral to litmus, and is obtained by action of an acid upon an alkali or a metal. Salts are called after the acids from which they are formed. The salt known as zinc sulphate is formed when zinc is added to sulphuric acid. At the same time hydrogen is set free. Common soda or sodium carbonate (Na_2CO_3) is produced when the hydrogen in carbonic acid is displaced by sodium. Bone contains much calcium phosphate ($(Ca_3PO_4)_2$), a salt formed by the substitution of calcium for hydrogen in phosphoric acid.

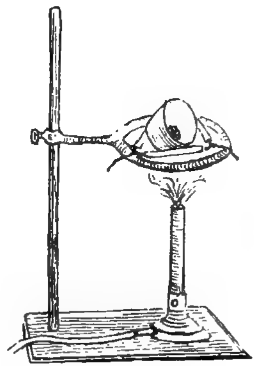


FIG. 9. Showing the method of estimating the mineral salts in flesh. A weighed piece is burnt in a porcelain cup until only the mineral matter is left.

When the body of a man is burnt, ashes remain which consist of mineral salts. Phosphate and carbonate of calcium remain as remnants of the bones. Sodium chloride, sodium carbonate, sodium phosphate, and in smaller amounts the corresponding salts of potassium, calcium, and magnesium, exist in all the fluids and tissues of the body. The salts are found in the food of man and are necessary for his existence. In the urine salts are excreted.

A solution of silver nitrate added to urine after the addition of a little nitric acid produces a white precipitate. This test shows the presence of *chlorides*. *A solution of ammonia* produces a white cloudiness in urine. This indicates the presence of calcium *phosphate*. *A solution of barium chloride* after the addition of a little hydrochloric acid produces a white precipitate in urine, indicating the presence of *sulphates*.

CHAPTER V

ELECTRICITY.

TAKE a stick of sealing-wax and rub it violently against a woollen stuff, such as the sleeve of your coat. Bring the stick near some tiny shreds of blotting-paper, and you will see that the bits of paper jump up and cling to the sealing-wax. By the work expended you have not only warmed the sealing-wax, but endowed it with the mysterious kind of energy known as electricity.

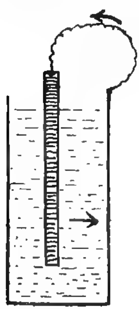


FIG. 10. Diagram of a simple battery.

Electric cells or batteries. Next take a tin can and fill it with a solution of caustic soda. You can buy a stick of caustic soda at the chemist's. Dissolve it in water. Obtain from the ironmonger's a small strip of sheet zinc, fasten this to a bar of wood, and place the bar of wood across the tin pot so that the zinc hangs in the solution of caustic soda. You have thus made a small electrical battery. Take it into a dark room and bend over the top of the zinc, till you can make it touch the outside of the tin can. Each time you apply the zinc to or withdraw it from the tin you may see a tiny spark. In the space between the zinc and the tin there is set up a condition of *stress* such as exists in a prodigiously greater amount between the earth and clouds during a thunderstorm. This condition of stress is partially relieved each time a spark or a flash of lightning darts across the space.

For a shilling you can purchase a more powerful battery (the Leclanché), such as is commonly used for the electric bells. It consists of a rod of zinc which dips into a glass full of a solution of chloride of ammonium. In the glass jar there is also a fixed rod of a black substance which is made of a mixture of powdered coke, black oxide of manganese, and shellac. At the upper end of the coke and the zinc rod respectively, there is fixed a brass binding-screw. Into each screw you can fix a piece of electric bell-wire. This is made of copper wire covered on the outside with a sheath of gutta-percha and waxed thread. Copper, like all metals, conducts electricity, while gutta-percha and wax are bad conductors or *insulators*, and prevent the spread of electricity from the copper wire to surrounding objects. Before fixing the wires to the binding-screws you must scrape off the insulating coat and clean the copper wire for half an inch, and then insert the bare ends in the binding-screws. Having done so, scrape clean the other ends of the wires, and bring these in contact. If the room be dark you will see a spark at each make and break of contact.

In such a battery, electricity is produced by chemical action, and so soon as the zinc rod is withdrawn, chemical action ceases, and sparks can no longer be obtained. When the wires are connected together, and the battery is at work, a flow of electricity is set up through the wire, from one binding-screw to the other.

This flow of electricity may be made to produce many effects. If a very thin piece of wire be interposed in the circuit, the electricity cannot easily flow, for the channel of conducting material is too narrow. Hereby such a condition of stress is set up that the wire becomes hot or even glows and emits light—the electric light.

Electrolysis. If the ends of the two wires from a powerful battery be dipped into a glass containing water acidulated with sulphuric acid, the flow of electricity will cause an evolution of bubbles of gas. The bubbles

will gather at the end of either wire, and if these bubbles be collected, it will be found that oxygen is given off from one wire, and hydrogen from the other.

The oxygen and hydrogen particles are driven in opposite directions, and thus, water is split up by electrolysis into its component elements. Acids, alkalies, and salts, when in solution, can be split up by the same means. If the elements thus produced have no tendency to combine either with the bare ends of the wires (*electrodes*), or with the liquid, they are set free. If the freed elements be gases, they collect into bubbles, and escape; if solids, they coat the surface of the electrodes. On this principle, articles can be plated with silver or gold by electrolysis.

Apply the two battery wires to the tongue, an acid taste will be produced, owing to chemical decomposition set up by the flow of electricity.

If the battery current be led through a coil of wire it *induces* a current of electricity in any other coil of wire happening to lie near. This *induced current* only occurs when the battery current is strengthened or weakened or made or broken. By employing many coils of fine wire twined round bobbins the induced current is made very powerful. Such an instrument is called an induction coil, and is used in physiology to *stimulate* nerves, muscles, &c.

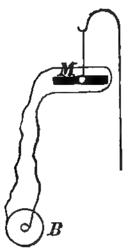


FIG. 10 *a*. Structure of a galvanometer. *M.* magnet; *B.* battery. A tiny mirror is fastened to the magnet, and a beam of light from a lantern is reflected from this on to a scale. Thus the movement of the magnet is magnified.

If the electrodes be applied over the biceps muscle, and a powerful current be employed, the muscle will contract on breaking or making contact; at the same time you will experience a pricking sensation in the skin.

Electric indicators. A small magnet, such as the needle in a compass, is affected by the neighbourhood of an elec-

tric current. If a magnetic needle be hung up by a silk thread in the middle of a vertical coil of wire, and an electrical current be sent through the wire from a battery, the magnet turns round.

On this principle, delicate instruments (indicators or galvanometers) are made by man to determine the presence or absence of electrical currents in any substance. Further than this, man has spun a spider's web of electric wires over the earth. Standing on one side of the world, the telegraph clerk in a few moments receives the currents despatched from the other side of the globe, and, by means of a code, translates the movements of the indicator into written speech.

Animal electricity. In the body of man, small electrical currents are produced whenever the muscles contract, the heart beats, or messages dart to and fro through the nerves. These currents are studied by means of electric indicators.

In certain fishes special organs have been framed for the production of electricity. By means of these they transmit powerful shocks to their enemies. The electric eel of the South American marshes, the torpedo in the Mediterranean, and the Malapterurus in the Nile, are famous for their electric organs. In veneration of its hidden powers, the Malapterurus is figured on the ancient Egyptian monuments. The common skate possesses the same kind of organ, but in this fish it is very poorly developed.

The study of animal electricity forms a special and very difficult branch of physiology. Electrical shocks are used by physiologists to excite the nerves supplying the different organs of the body, so as to determine the influence of the nerves and the functions of the organs.

CHAPTER VI

ATMOSPHERIC PRESSURE.

We cannot see the air, but the wind waving the trees and blowing against us makes us sensible of its existence. Try and force a tumbler, mouth downwards, into a basin of water. The air opposes the water's entrance. Tilt the tumbler, and see the bubbles of air escape from it, and the water rise up in it as this happens. Take a piece of glass tubing about 18 inches long, and hold the middle inch or two in an ordinary fan-tailed gas-burner till it bends and becomes U-shaped. Introduce some water coloured with ink within it. The water stands at the same height in either limb. Suck on one end, the water rises in that limb and falls in the other. Blow, and the reverse happens.

Put one end of a straw under water and suck on the other. The water rises up the straw into your mouth. These effects are due to the pressure of the air.

All forms of matter have weight—solids, liquids, and gases. A sea of gas presses on the earth, and is attracted or pulled towards the earth by gravity. Below this sea we live. The weight of the atmosphere is such that it presses on every square inch of the surface of the earth and upon every square inch of everything that is upon the earth, with a pressure which is equal to that of a 15 lbs. weight (1·033 kilogram on each square centimetre at the level of the sea). The *pressure of the atmosphere* varies according to its height; thus it is much less on the summits of high mountains, greater at the bottom of deep mines. Owing to winds, the effect of the sun's heat, and various other causes, the pressure varies continually from day to day.

The barometer. The pressure of the atmosphere is not apparent to our senses, but with a barometer we can

measure it. The barometer is an instrument acting like a balance ; it is usually made of a tube bent up at one end and so forming a long limb and a short limb. The long limb is more than 30 inches or 760 mm. in length, and is closed at the top, while the short limb is open. The tube thus constructed is completely filled with mercury, a fluid so heavy that its density is more than thirteen times as great as that of water. After the mercury has been boiled in the tube so as to expel any bubbles of air, the tube is placed in the vertical position. So soon as this is done the mercury in the long limb sinks a little way and then remains stationary at a height of about 30 inches or 760 mm. The atmosphere cannot press on the upper surface of the mercury; on the other hand, the atmosphere presses with its full force on the lower surface of the mercury. This pressure is sufficient to support a column of mercury about 760 mm. in height. The space at the top of the mercurial column contains no air, it is empty save for a little vapour of mercury, and is termed a *vacuum*. If a glass syringe be connected by a piece of rubber tubing with the open end of the short limb of the barometer, the height of the mercurial column can be raised or lowered by forcing air against or sucking it from the surface of the mercury. The atmosphere can support a column of water more than thirteen times as long as that of mercury, i. e. about 33 feet.

FIG. 11. Barometer.

To prove the pressure of the atmosphere the student can carry out the following experiment :—

A barometer tube can be bought for 1*s*. Fill it with mercury holding the open end highest and pouring the mercury in through a small funnel. Tap the tube to expel air bubbles. Close the open end with the thumb and place it under mercury

in a basin. Hold the tube erect and measure the height of the column of mercury. Robert Boyle, who invented the air pump, and was one of the founders of the Royal Society in Charles II's time, placed such a mercurial barometer under the bell-glass of his pump, and noticed that the column of mercury fell lower and lower as he exhausted the air, and rose again when he let the air in again.

The influence of the atmospheric pressure. The effect of heat on the state of matter is affected by the atmospheric pressure. For example, water expands when changing into ice, and the expansion of the water is resisted by the weight of the atmosphere. Thus, if the pressure of the atmosphere in any vessel be artificially made greater, water can be cooled below zero without freezing. Similarly, when water boils at 100° C., the escaping molecules of water vapour tumultuously rise up through the water and bombard and drive away the molecules of the atmosphere which press against them. Boiling takes place whenever the pressure upwards from the water equals the pressure of the atmosphere upon the water. At Quito, which is situated 9,540 feet above the sea, the atmospheric pressure is lessened, and water boils there at 90·1° C. If water be enclosed in a strong iron boiler provided with a safety-valve, it can be heated considerably above 100° C. By the inability of the vapour to escape the water is prevented from coming to boiling point, for the pressure of pent-up molecules of steam impedes other molecules of water from becoming steam. It is on this principle that boilers are made for such purposes as the extraction of gelatine from bones, the disinfection of clothes, &c., by means of super-heated steam.

Owing to the pressure of the air a syringe or pump becomes filled with water when the piston is drawn out. Similarly, a baby sucks its bottle by enlarging its mouth, and thus making the pressure within less than that without.

By the excess pressure of the atmosphere the milk is forced up the tube. Likewise at each breath we enlarge our chests, and the pressure of the atmosphere driving air down the windpipe distends the elastic bags or lungs which lie within.

Vapour pressure. When a liquid is confined in a vessel some of its molecules escape into the space above its surface as vapour or gas, and this vapour exerts pressure. If a little water be introduced into the vacuum at the top of a barometer, the column of mercury falls, owing to the pressure exerted by the vapour. The higher the temperature of a liquid the greater becomes the vapour pressure, for the molecules when heated move with greater rapidity, and thus bombard with greater force the walls of the vessel in which they are contained.

Take two barometer tubes and fill them with mercury. Shake out all air bubbles, close the open end of each with the thumb, invert and place the open end under mercury in the basin. Each column stands at the same height about 760 mm. above the level of the mercury in the basin. Fill a pipette *C* with water by sucking, close the upper end with thumb, insert lower end under lower end of *B*, and by slackening pressure of thumb allow a drop or two of water to enter *B*. The water rises to the vacuum, turns into vapour there and the mercury falls in *B* to a lower level than in *A*. Heat the upper end of *B* with the hand, the mercury falls still lower.

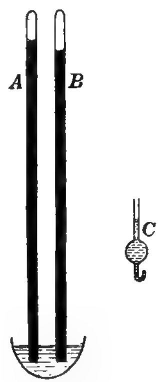


FIG. 11 *a*.

The enormous pressure exerted by steam is illustrated by the bursting of iron boilers. By the invention of the steam-engine man has turned this pressure to his own use, and by thus drawing on the potential energy stored in the fuel of the world increases a thousandfold his power of doing work.

From our moist lungs and skin water vapour is continually passing away; we are cooled when heated by the evaporation of the perspiration. To convert one gramme of boiling water into steam it takes 537 calories of heat. The heat becomes latent or hidden away, converted into the increased movement of the molecules.

From the warm surface of our bodies the molecules of water continually evaporate into the air. The higher the temperature the more rapid is the velocity of the molecules; thus ink dries rapidly on a hot dry day, and slowly on a cold damp day. In the latter case the air is saturated with water vapour, and almost as many molecules of water strike the ink as escape from it. The *dewpoint* is the temperature at which the aqueous vapour present in the air is sufficient to saturate it. The dew on grass and cobweb comes from the cooling of the air. The earth on a clear night radiates its heat away into space and cools the air next it until the saturation point is reached.

On a wintry day you can see clouds of steam blown from the nostrils and rising from the body of a heated horse. The vapour rising from the warm body is condensed by cold into a wet mist of droplets which form upon the dust particles floating in the air. If the air be nearly saturated with water vapour, the evaporation of sweat is checked and we feel the weather to be heavy and muggy. On the other hand, when the air is very hot and dry, the evaporation from our lungs and body is too great and we suffer discomfort. Not only the rain but the beauty of the world, the soft misty colouring of the landscape, and the fleecy clouds of the heavens, are due to the condensation of water vapour on the particles of dust which everywhere pervade the atmosphere. The air is heated and so expanded, and lightened, by the sun-warmed earth, it also receives water vapour evaporated by the sun's heat and this lightens the air, for steam is lighter than air.

Thus it rises to loftier and colder regions, and there becomes saturated with water. Then the water particles condense into clouds.

The body of man is built to live at the bottom of a sea of air. Each organ has been evolved to the minutest detail, so that the whole may act perfectly in an atmosphere pervaded with dust and water vapour. Only within certain limits can man change his place and climb to lofty mountains, or burrow into the bowels of the earth. At the top of the Alps the barometric pressure is half that on the plains. If he ascend too high in a balloon, or in a diver's dress seek to fathom the secrets of too deep a sea, he must die, for the pressure of the oxygen in the air in the one case is too little, in the other, too great for the continuance of life. At 100 feet depth in the sea air must be pumped into the diver's dress at a pressure four times that of the atmosphere, to keep the water out, for each 33 feet of water equals 1 atmosphere.

If life should exist in another planet such as Mars, the physiologist knows that such life must have been evolved on some quite different structural plan to that which has controlled our life. In Mars, the differences of temperature, of atmosphere, of the force of gravity, would make life similar to ours impossible.

Somewhere in the infinite universe there may be another planet circling round another sun, resembling the earth in size, illuminated and warmed to the same degree. Should it be that such a planet was subjected to exactly the same physical conditions as is the earth, there life, as we know it, might exist.

CHAPTER VII

LIFE.

Life. Our fundamental notion of a living thing is that it moves spontaneously and reacts to stimulation. If we meet with a man lying prone and motionless on the ground, we call to him or touch him in order to see if he will respond, and thus to know whether he be ill, or drunk, or dead. If by these means we get no response, we ascertain whether he be warm, whether his chest rise and fall with respiration, or we place our ear upon his chest and listen whether his heart beat. If these signs of life be not found, we may finally open an artery and see whether the blood flows. Should this last sign of energy be absent we determine that the man is dead. It is not only life, however, that is distinguished by movement. Nevertheless, so strong is the primitive idea that associates life and movement that we find poets personify the winds and waves, while children and savages regard the steam-engine as a living being, and dread with instinctive fear all objects endowed with mysterious movement.

If we take a stick of sealing-wax and rub it with a piece of silk and apply it over some little bits of paper or downy fluff, the latter will be agitated with motion, and under its influence will fly up to the rod, and leap from the table; but we know that life is not signified here.

Observing the daily life of a kitten we should find she eats and drinks, now sleeps, now actively ranges to and fro. She breathes, her chest rising and falling with ceaseless regularity, casts forth at times waste products, urine and faeces, grows in stature and weight, and finally becomes

a mature cat and produces her own kind. We find also that she is responsive to stimulation, though we cannot foretell with certainty what that response may be.

A living organism then, such as a cat or man, eats and excretes, breathes, feels, and moves, grows and develops, and propagates its own kind.

In certain conditions life becomes latent or hidden, and then it is a far more difficult question to determine whether an object is alive or not.

Think of a snake lying on a roadside, numbed, apparently dead with cold; or of a chrysalis dug from the ground; or of a hard, dry pea. If you take the snake into a warm room it may spring into active life and bite you for your pains. If you keep the chrysalis, one day it will emerge, as it were from the tomb, and flit away a resplendent butterfly. The pea when planted, warmed by the sun, and watered by the rain, grows to be a plant, blooms, seeds, and produces its own kind. Is a pea alive? This is a difficult question to answer. In the middle of forests when a clearing has been made flowers have sometimes sprung up which are not found within a hundred miles or more. In particular this has happened where the foundations of some old Roman villa lay. These seeds, it is believed, have lain dormant in the ground ever since the Roman period.

Flower seeds have been kept for days in a chamber at a temperature of $-200°$ C. (This extreme cold can be produced by the evaporation of liquid air.) At this temperature all chemical activity ceases. In spite of such exposure, the seeds, when planted in the open, germinate and grow with unabated vigour. Similarly, seeds have germinated after lying for long periods in a vacuum chamber. During such periods nothing has appeared in the vacuum, no sign of chemical change in the seeds has been evidenced, life has remained absolutely latent. The seed preserves a certain structure, and when soaked

with water and warmed, then, and then only, does the energy of the life within become manifest.

The elementary structure in which life is made manifest. An old Greek physician, Hippocrates, thought that the body of man was compounded of blood and phlegm and gall. In the Middle Ages, the alchemists, surrounded by acolytes and attendants, hung expectant over crucibles placed in their dark and mysterious laboratories. They sought, but sought in vain, for an homunculus or little man to spring into being. It was to be compounded of the strange mixtures which they purified in their retorts. Not less bold were the attempts which were made about thirty years ago to prove the spontaneous generation of life from infusions of decaying matter. It is still a matter of popular belief that maggots are bred of filth, frogs of slime and mud. It is nevertheless an absolute and assured fact that life only springs from life. *Omne vivum ex ovo:* every living thing grows from a germ or egg separated from the body of its parent. Likewise the matured offspring is always similar to its parent. From the egg of a hen there springs a chicken, never a gosling, nor a duckling. From the egg of an adder there emanates an adder, never a bird. Popular confusion and superstition have arisen, owing to the fact that the immature offspring do not at first resemble the parents; thus the eggs of a silkworm moth become silkworms. The silkworm after a period of growth turns into a chrysalis, and this into a moth.

Similarly, if you took an egg from under a broody hen after it has been hatching for three days, and opened it, you would find inside a little, immature, but living form, totally unlike the soft downy chick which finally pecks its way out from the shell. Life has many stages; the growth of each living thing is largely hidden from super-

ficial observation; the mystery of this growth is unravelled by the study of the development of the egg.

The house of life is built up in all cases of minute structures called cells. Throughout the range of living things we find animal or plant framed either of a single cell, or of myriads of cells built into tissues and organs.

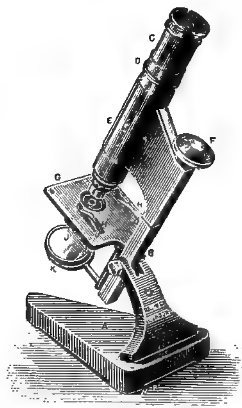


FIG. 12. Star microscope. Made by Beck & Co., Cornhill, E.C. The student of physiology must make every endeavour to obtain the use of a microscope. At the top of the tube CDE is the eye-piece; at the bottom the objective. J is a mirror for reflecting light on to the object. F is a screw for adjusting the focus.

In studying the lowest of all living forms we reach a point where animal life mingles with plant life, the two becoming almost indistinguishable. The common stock from whence the two great branches of the tree of life have sprung is the group of one-celled organisms.

Unicellular organisms. The amoeba. As a type of such we may take the amoeba[1]. This is a tiny creature, in size not more than $\frac{1}{100}$th part of an inch, found in water containing decayed matter. It is necessarily only visible to us under the microscope, and to see it properly we must use an instrument powerful enough to magnify a pin's head into the size of a cart-wheel. It then appears as a mass of jelly-like substance, studded with small granules. This substance we call *protoplasm*, a word mean-

FIG. 13. Glass slide and cover slip for mounting microscopical specimens.

[1] A tube containing amoebae can be obtained from T. Bolton, 25 Balsall Heath Road, Birmingham.

ing from its derivation the primitive or first stuff. Seeking among decaying leaves or on rotten wood it is now and again possible to find masses of protoplasm visible to the naked eye. Here thousands of amoeba-like cells fuse together and form a network which slowly moves, or rather flows, like an ill-set jelly, here or there. On watching an amoeba under the microscope, it can be seen to creep about upon the glass slide on which it is placed. Its protoplasm consists of a fine foam or honeycomb structure. Between the bars or fibrils making up this structure there lies a clear glassy fluid-substance, while in the bars of the honey-

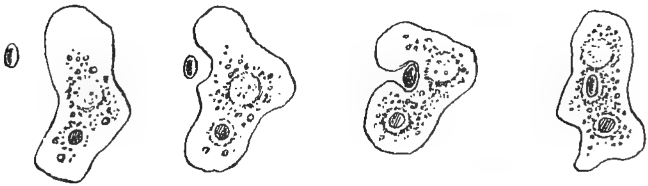


FIG. 14. Microscope, high power. The amoeba taking in a particle of food. The changes are shown in four stages. After Verworn.

comb itself there lie formed elements or granules of different kinds. These are always placed at the angles or knots of the network. As the amoeba moves it can be seen that the clear glassy substance flows out of the spongework and forms processes now at one place, and now at another. The clear substance is known as the *hyaloplasm*, while the spongework is termed the *spongioplasm.* Within the amoeba there may be sometimes distinguished a round spot which is known as the nucleus. The nucleus can be seen with great ease if the amoeba be stained with some coloured dye, such as blue ink. Like the rest of the cell, the nucleus is made of a network, within the meshes of which there lies a fluid transparent substance. The bars of the network contain granules of *chromatin,* a coloured substance, and one which stains

very darkly with dyes. Another structure may also be visible. This is a clear round space filled with water which slowly grows larger, then suddenly contracts, and disappears to gradually reappear once more. This is the *contractile vacuole.*

The life of the amoeba, as it is passed in a drop of water, can be observed by patient microscopic observation.

It continually moves, extending out processes from its body and flowing into those processes. If excited by an electric shock, the amoeba contracts into a round ball. The amoeba flows round and thus devours any smaller organisms which may be swept against it by currents of water. Such food material is dissolved and digested by special juices to be *assimilated* or built up into the protoplasm of the amoeba. From indigestible material the amoeba flows away. In its watery habitation the gases of the atmosphere are dissolved, and by means of the rhythmic contraction of its watery vacuole the amoeba breathes, taking up from the surrounding water oxygen, and giving forth into it waste materials.

In every drop of your blood there may be found, under the microscope, colourless cells closely resembling the amoeba in structure but smaller than it; endowed with the same powers of movement, of flowing round and assimilating particles.

Such cells as the amoeba, when they grow to a certain size, simply divide into two parts, each of which becomes an amoeba in itself. Thus the parent merges into its progeny. Life will only continue to be manifest in an amoeba under certain conditions. If the water in which it lives be heated to 40° C.—that is, just above the temperature which we can comfortably bear in a hot bath—the amoeba becomes stiff and dead. If the water be frozen, the amoeba ceases to show any sign of activity, but may be revivified by warmth.

In pure distilled water the amoeba cannot live, the water must contain traces of certain salts in solution as well as oxygen. Many chemical substances will, if added to the water in which an amoeba is placed, act as poisons and instantly kill it.

CHAPTER VIII

SUN-ENERGY AND PROTOPLASM.

Formation of protoplasm by plants. Owing to the growth of organisms, rain-water, when allowed to stagnate in water-butts, frequently becomes green in colour. The germs of these organisms float as dust in the air and are washed down with the rain. In such water there may generally be found a unicellular organism known as the haematococcus. It appears under the microscope as an oval cell of a bright green colour which is here and there flecked with red. As the haematococcus is about the size of the amoeba it may be taken as the type of a plant-cell, and its life history contrasted with that of the animal-cell amoeba.

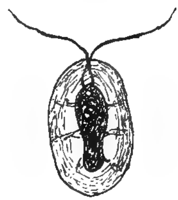


FIG. 15. Microscopical appearance of an haematococcus.

When the haematococcus is at rest there may be seen prolonged from its cell-body two protoplasmic lashes or *cilia*. These cilia lash the water, and by their means the haematococcus is propelled through the water in the same way as a paddle propels a boat. The soft protoplasmic substance within is enclosed by a cell-wall formed of a material called cellulose, similar in nature to the fibre of cotton or the bark of trees. The cell is coloured with chlorophyll, a substance to which the green colour of all plants is due. Lying within the cell-protoplasm are granules which give the characteristic tests for starch.

Starch ($C_6H_{10}O_5$) is a definite chemical compound composed of the elements carbon, hydrogen, and oxygen. It can be turned into grape-sugar ($C_6H_{12}O_6$) by boiling with diluted sulphuric acid. Cellulose can also be turned into

grape-sugar by the same means. Starch, cellulose, and sugar are bodies allied in composition, and are termed *carbohydrates.*

The haematococcus, enclosed as it is by a cell-wall, has not the power to flow round and so eat particles of food in the way the amoeba does. It lives in impure water, surrounded by a very weak solution of chemical elements (oxygen, nitrogen) and compounds (carbonic acid and salts such as chlorides, phosphates, nitrates, and sulphates of sodium, calcium, potassium, &c.). These compounds may be obtained as a residue by evaporation of large quantities of water.

If water containing green organisms be exposed to sunlight, bubbles of gas are given off; and these, if collected and tested, are found to be composed of oxygen.

This oxygen is derived from the decomposition of carbon dioxide. The decomposition is effected by the activity of the green organisms. Carbon dioxide exists in traces in the atmosphere and is readily dissolved by water. This gas is formed and enters into the atmosphere whenever compounds containing carbon undergo combustion. Energised by the sun's light and heat acting through the chlorophyll, the protoplasm of plant-cells is able to tear the carbon apart from the oxygen. The oxygen escapes into the atmosphere, while within the plant-cell there arises from the combination of oxygen, hydrogen, and carbon, a new complex compound—carbohydrate. During this process a great deal of sun-energy becomes latent. Carbon and oxygen, hydrogen and oxygen, for ever strive to unite to form carbon dioxide (CO_2) and water (H_2O). By the plant-protoplasm and the sun's energy these elements are torn apart and held in a state of stress in the complex molecule of carbohydrate ($C_6H_{10}O_5$). This energy reappears as light and heat when carbohydrate is burnt (heated in the presence of

oxygen), for then the compound is broken down, the state of stress relieved, carbon dioxide and water formed.

The carbohydrate, after it has been formed in plant-cells, may be stored away as a reserve supply of food, or may at once be compounded with nitrates or salts of ammonia to form still more complex compounds. These salts dissolved in the water are soaked up by the plant. Next, sulphur compounds may enter into combination, and the compound within the plant-cell becomes more and more complex, until it ultimately becomes part of the living protoplasm. To manifest life, protoplasm must be wet with water, in contact with oxygen, and warmed by the sun's heat to a certain temperature.

The chemical nature of protoplasm. The chemical structure of the molecule of living protoplasm is hidden from us, for the moment protoplasm is subjected to analysis it ceases to live, crumbling into simpler substances. The amoeba-like white cells of the blood can be collected in sufficient amount and analysed after death. They are then found to yield a very complex substance named *proteid.* A familiar example of a proteid is white of egg. Egg-white forms a store of food material set by for the growth of the tiny living germ-cell or ovum, which ultimately grows into the chick. Such a proteid, when broken down by heat into its constituent elements, is found to contain carbon, hydrogen, oxygen, nitrogen, and sulphur.

In 100 parts of proteid these elements occur in about the following proportions :—

Sulphur	1
Hydrogen	7
Nitrogen	15
Oxygen	23
Carbon	54
	100

You can remember these numbers as :—
S 1, H 7, N 7×2, O 7×3, C $7 \times 7\frac{1}{2}$.

Proteids are known which contain iron, phosphorus, or iodine, in addition to the above elements. Beside proteid, protoplasm yields much water, for it is in itself a semi-fluid substance.

The proteids can be broken down by boiling with hydrochloric acid, or by the action of the ferment in pancreatic juice, into a diversity of simpler bodies called amido-acids. Amido-acetic acid is the simplest of these and its relation to alcohol and acetic acid is shown.

$CH_3 \cdot CH_2OH$	$CH_3 \cdot COOH$	$CH_2 \cdot NH_2 \cdot COOH$
alcohol	acetic acid	amido-acetic acid or glycin.

The NH_2 group gives an alkaline property like ammonia (NH_3), while the COOH gives an acidic property. Thus proteids can combine both with acids and alkalies. Recently the amido-acids have been linked together by the chemist to form compounds called polypeptides, which possess many of the properties of proteids. The chemist is thus on the way to make a proteid.

Tacked on to the semi-fluid protoplasm there are minute quantities of mineral substances such as phosphates and sulphates of potassium, calcium, and magnesium, chlorides and carbonates of sodium. Perhaps some of these are chemically combined with the proteid to form the complex molecule of protoplasm. From white blood-cells there may also be obtained a small quantity of carbohydrate and of oil or fat. These substances are probably stored up in the protoplasmic network or spongioplasm as a reserve supply of food material.

From the body of a man exactly the same substances may be extracted—proteids, carbohydrates, fats, water, and mineral salts. In the following way the chief ingredients may be shown which go to make up the average man weighing 150 lbs. A large glass jar holds the 91 lbs. of water which his body contains, while in other jars are placed 18 lbs. of dried white of egg and a little less than 9 lbs. of gelatine: these together represent the proteids of the body. Other jars contain respectively 21 lbs. of fat

and 3 ozs. of sugar and glycogen. Still other jars hold $8\frac{1}{4}$ lbs. of phosphate of lime, 1 lb. of carbonate of lime, 6 ozs. of phosphate of magnesia, 4 ozs. of fluoride of lime: these represent the mineral salts of the bones. Lastly, there are jars containing a few ounces of chlorides of sodium, and potassium, and four iron tacks.

Liberation of energy by protoplasm. If the dead body of a man be cremated in a furnace the heat drives off the moisture as steam, and in the presence of oxygen breaks up the proteids, carbohydrates, and fats into carbon dioxide, water, and ammonia, the proteids yield the last. When these have disappeared into the atmosphere in the form of vapour or gas, as similarly occurs in the case of the combustion of coal, only a small amount of incombustible mineral ash is left behind. Much heat is produced by the combustion of the body, for energy is liberated when carbon and hydrogen are relieved from stress and are set free to unite with oxygen as carbon dioxide and water. When a dead body is buried in the ground and decays, carbon dioxide, water, and ammonia are formed by the growth and influence of bacteria. Here again the same process of combustion takes place, only at a much slower rate. The loss of heat by the decaying body is so gradual that to the touch no sense of warmth would be conveyed. But in the case of a gardener's hotbed made of rotting manure, the process of decay or slow combustion is sufficient in amount to produce an appreciable degree of heat. Thus soldiers in times of war, when perishing with cold and exposure, have been known to creep into manure-heaps in order to obtain warmth and sleep. The total energy given up by a dead body is the same, whether it be burnt in a crematorium, or slowly decay in the ground.

Coal is a very impure form of carbon containing in addition small quantities of oxygen, hydrogen, and

nitrogen. It is the hardened vegetable deposits of ancient forests and morasses. When coal is burnt, the energy set free by combustion may be employed to warm a room, or used to turn water into steam and produce pressure within a boiler. The pressure of the steam can be employed to drive an engine. The engine, in its turn, can be used to do work, or for the production of electricity. The electricity can, in its turn, be employed to produce heat or to light a town. Thus the energy stored up in the coal which, ultimately derived from the sun, was rendered latent by the growth of ancient vegetation, is converted by man into energy of heat, movement, light, electricity. Our houses are warmed and lit, food cooked, steamers and trains propelled by the energy of the sun which irradiated the earth in past ages. This energy it is man's bounden duty not to wastefully use. In the presence of oxygen, living, warm, and wet protoplasm is constantly undergoing combustion, with the production of carbon dioxide, water, and other simple compounds. The energy thus liberated in protoplasm may appear as *heat*,—our bodies are warm ;—as *electricity*,—the electric eel can give a powerful shock ;—as *light*,—the lamp of the glow-worm's tail ;—but more important than all as *energy of movement*.

Protoplasm is an immensely complex and unstable chemical compound. Imagine a tall tower of bricks built by the energy of a child ; the tower sways and thrills with every slight touch, but if well built still hangs together, balanced and complete. A more violent blow may shatter the whole ; the tower falls ruined to the ground, and its place is taken by scattered, insignificant heaps, or isolated bricks. So long as the tower stands firm, bricks may be added or taken off here and there ; some of these changes may render the structure more stable, while others may make it less so.

So with the molecule of protoplasm. It is a tower of

chemical atoms built and compounded together by the sun's energy. The thrill and tremble of protoplasm we call life. Protoplasm, combined with oxygen and shaken by waves of energy from external sources, undergoes chemical decomposition and yields up carbon dioxide, water, and simple nitrogenous compounds. By this decomposition the latent energy of the sun is once more set free, and appears in protoplasm as the energy of life.

Protoplasm, so long as it is moist and warm, is continually tending to decompose; to maintain its existence new compounds must be as continually added in the form of food. Waves of light, of sound, of heat, of electricity, for ever beat against protoplasm, other forms of matter are driven against it, other masses of living protoplasm seek to devour it, life continues in a universe of unrest. Engulfed by too violent a storm of energy, protoplasm dies, its molecule is broken, is separated into simple and more stable compounds, and then finally returned to water, carbon dioxide, nitrates, and other simple salts. A plant energised by the sun can once more build up these simple bodies into unstable living protoplasm. Animals cannot build up such elementary substances. They live and grow by devouring and assimilating the complex products of plant life.

Grass is formed from elements of earth, water, and atmosphere, compounded by the sun's energy which becomes latent within. Sheep eat grass and men eat sheep. The energy of our bodies drawn from sheep is taken by the sheep from the grass, and primarily derived from the sun. The bodies of animals finally decompose into elementary substances, these again become food for plants. The energy of animals is finally dissipated as heat. Thus the cycle of life proceeds.

and as dust are thus wafted all over the face of the earth. Wheresoever the spores fall on to a suitable fluid they germinate and become bacteria. It is owing to this fact that infection is spread from man to man.

The biting of insects has recently been proved to be one of the commonest methods of infection. The insect bites an infected animal and carries the poison to another which it bites and so infects.

The plague bacillus is spread by fleas, yellow fever by mosquitoes, malaria by mosquitoes. By preventing this source of infection the spread of these diseases has been checked. This is one of the most wonderful and useful of modern discoveries.

Use of bacteria. Bacteria exist everywhere, in water, in earth, in dust, swept into the air by winds, falling to the ground in rain-drops. The broom of a housemaid raises myriads from our carpets, we devour myriads in food, drink myriads in water, and breathe in myriads from the air. All dead organic matter is broken down by the agency of bacteria into simple chemical substances. These substances are thereby rendered fit for the food of plants. Thus the face of the earth is cleansed and made sweet for life. If it were not so, the dead bodies of animals and forms of plant life would strew and cumber the ground until life became choked under the débris of death.

The nitrogen supply for the building of proteid depends entirely on bacteria. Nitrification bacteria live in the soil and turn urea into ammonia and this into nitrates. Denitrifying bacteria in the soil split up nitrates and return nitrogen to the air. On the rootlets of certain plants like peas, beans, lupins, there are swellings in which live bacteria which have been proved to take nitrogen out of the air and make it available as nitrates for the plant.

As scavengers of the world the bacteria have inestimable value. To confine them to this duty, to stop them from invading and destroying living organisms, is one of the greatest and most important tasks on which man is now most busily engaged. By the study of bacteriology man

may in the future sweep away those scourges of humanity, the infective diseases. Our children or children's children may live knowing not the dread of scarlet fever or consumption; just as we, owing to the work of Jenner,

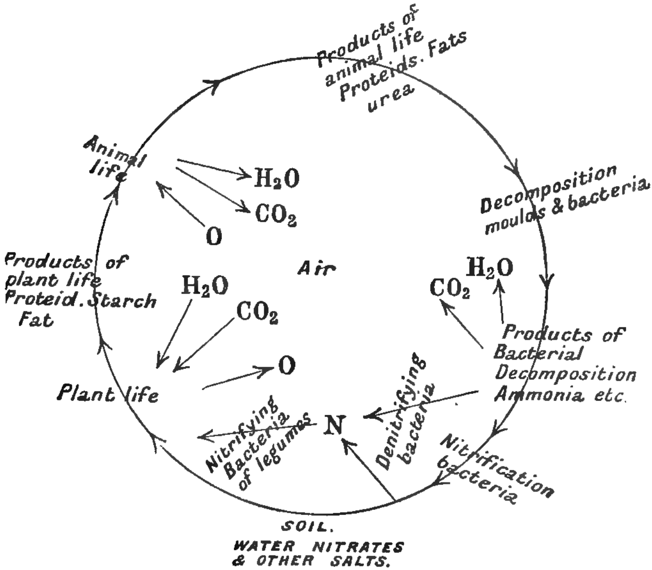


FIG. 16*a*. The arrows show the materials which plants, animals, and bacteria take up and give out to the world.

who discovered vaccination, are freed from the daily fear of small-pox.

It has been found possible to strengthen the natural defence of the body against the invasion of certain bacteria, such as tubercle bacilli (the cause of consumption), by injecting under the skin the minutest dose of the bacilli in question which have been killed by heating. The dose used is the thousandth part of the thousandth part of a gramme!

Sterilisation. By bacteriological research we learn how to preserve food. The bacteria flourish only under certain conditions of temperature. In cold chambers meat can be indefinitely preserved and carried in ships from the colonies to England. Boiling or roasting destroys

bacteria; thus milk or water can be sterilised (rendered free from bacteria) by boiling.

Stand a bottle of milk in a pot of boiling water and thoroughly boil it, then cork up the bottle by a plug of cotton-wool which has been for one moment singed in a flame. Next day boil it again to kill any spores which may have developed: the milk will keep sweet so long as you like to keep it. The boiling destroys the bacteria and their spores, the singeing of the cotton-wool destroys the bacteria or spores which mayhap stick to the wool. The wool-plug acts as a filter and prevents the passage of bacteria from the air into the bottle.

Numberless foods are now sterilised and preserved in tins and bottles. Bacteria will not grow in the absence of moisture, so dried foods can be kept indefinitely without need of any further precaution.

Many infective diseases are spread by contamination of milk or water. Infection can be largely prevented by the simple precaution of boiling all milk and water used for drinking purposes. *Filters for water are as a rule worse than useless,* for the bacteria grow and multiply in and through the pores of the filter.

Antiseptic treatment of wounds. There is a certain bacterium which lives in the earth. This, if it gain a foothold in the body of man, may multiply and produce tetanus or lock-jaw. Fortunately oxygen is a poison to this bacterium, and it very rarely gets a chance of growing. Other bacteria produce inflammation and prevent the healing of wounds. The tissues have a natural power to resist the invasion of bacteria. Wounds should not be washed with water, for water damages the wounded tissues, and also, if unboiled, may infect the wound with bacteria. In the natural method of repair the wounded place dries, and is covered with a scab under which repair goes on. The surgeon finds dry clean cotton wool the best thing to cover a wound with, and then he keeps the wounded place quiet and untouched. If he must wash the wound he uses

boiled sterilised water containing as much salt as there is in blood, viz. 0·8%. This does no harm.

The behaviour of unicellular organisms. The behaviour of such unicellular organisms as amoebae and bactèria under varying external conditions forms a most fascinating branch of physiological study.

While such are under microscopical observation, the effects of heat and cold, electricity, light and dark, and of chemical reagents, may be watched and recorded. Certain bacteria always seek to be at the top of a culture-tube, and resist the pull of gravity; others crowd to the bottom. Some love the sunny and some the shady side of things. One class of bacteria, e. g. nitrification bacteria, can only grow and flourish in fluids containing oxygen gas in solution; another class, e. g. denitrifying bacteria, shun this gas as a poison, and, growing in the depths of putrefying material, obtain oxygen and all else that is necessary for life from the débris of decay.

Unicellular organisms are repelled by certain chemical substances, attracted by others. If a particle of decaying matter be added to a drop of water in which infusoria (animal-cells larger than amoebae occurring in infusions of decaying matter) are scattered, these little animals may be seen under the microscope to lash their cilia and paddle in crowds up to the food-stuff. A grain of quinine, on the other hand, repels these organisms to the farthest limit. Infusiora called *paramaecium* may be obtained for examination from the contents of the rectum or hind part of the intestine of a frog.

Similarly, if a capillary (fine as hair) glass tube be inserted under the skin of a frog, white blood-cells are attracted or repelled according to the nature of the chemical substance placed within the tube. These cells may be observed to seek and devour bacteria, for they form an army of warriors set to defend the coasts of the body from the entry of such foes.

It is curious that organisms can be slowly trained to live

in chemical solutions which are of a deadly strength. Thus amoebae are instantly destroyed when plunged into water containing 1 per cent. of common salt, and yet by very slowly increasing the strength of the salt they may be brought to survive in a 4 per cent. solution. So De Quincey, the opium-eater, trained himself to take doses of opium which would be fatal to an ordinary man, and the habitual drunkard soaks his protoplasm with alcohol in place of water, until he can quaff with impunity (for the time being) poisonous draughts of neat spirit.

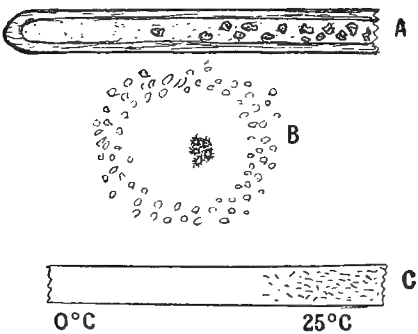


FIG. 17. Microscope, high power. A. White corpuscles are seen creeping up a tube and devouring bacteria. B. A drop of water containing infusoria. The clump in the middle has been killed by the touch of a hot needle. the others are flying from the dead bodies. C. A capillary glass tube containing bacteria. One end is heated to 25° C., the other end cooled to 0° C. The bacteria have crowded to the warm end.

By the addition of traces of chloroform to their watery habitat, unicellular organisms may be thrown into a quiescence which, if continued, ends in death. From temporary chloroform *anaesthesia* the organisms can be recovered by a bath of fresh water. Carbon dioxide gas poisons amoebae and infusoria, while a stream of oxygen bubbled through the water will revive their activity. If some infusoria be killed (by touching the drop of water in which they are being observed with a hot needle) the live ones will fly from the corpses of the dead. Placed in a drop of water boiled free of oxygen, these animals will seek a piece of blotting-paper placed at the edge of the drop and wetted with water containing oxygen in solution. Placed in a tube of water, one half of which is covered with dark paper and the other exposed to strong sunlight, the infusoria will seek the shade. If one end of the tube be

warmed or frozen, they will fly from too ardent heat or cold, and seek water which is at the ordinary summer temperature.

Certain unicellular organisms are known which, by blowing out little gas-bubbles, lighten the density of their protoplasm ; and thus when calm weather prevails they rise to the top of the sea. So soon, however, as the sea becomes boisterous they expel the bubbles and sink to the bottom. It is wonderful to observe the long processes or filaments of protoplasm which stream out from such organisms known as *rhizopods*. These never coalesce with each other, or with the processes of a similar organism, but withdraw on the slightest contact. Here the protoplasm feels, is repelled, and streams in the opposite direction. However, should food material come within contact, the protoplasm feels and is attracted, and, by streaming round, encloses the food.

More than this, if a single protoplasmic process severed from a rhizopod come in contact with a similar but unknown rhizopod there will be no coalescence here. Let it, however, touch that from which it was severed, and it will immediately be seen to coalesce and become a part again of the whole.

It is thus abundantly clear that what we term the power of choice or free will is implanted in the lowest living organisms. They choose their food, select one mineral salt or another, and secrete perchance a lime or a silica shell, seek the light or the dark, warmth or cold, and betake themselves to one or other electrode when a current of electricity is sent through their watery habitat. Different organisms exhibit different habits of life, and thus, although life is always manifested in protoplasm, the slight difference in this manifestation proves that the structure of the protoplasmic molecule must be slightly varied in each species of cell ; hence one man's meat may be another's poison.

CHAPTER X

DIFFERENTIATION OF STRUCTURE AND FUNCTION.

The hydra. Adhering to the water-weeds of ponds there may be found little white, yellow, or green bodies of the thickness of a cotton thread and about three or four millimetres in length. These are water polypes (*Hydra vulgaris*). They afford us a simple type of a many-celled animal. The hydra has a body, a mouth leading into a hollow gut, and a number of tentacles. By means of its tentacles it seizes upon water-fleas and conveys them into its mouth. It can bend its body, contract or expand its tentacles, and slowly crawl along. The structure of a hydra can be made out by cutting it from top to bottom into thin sections, and examining these under the microscope. Examining such a section

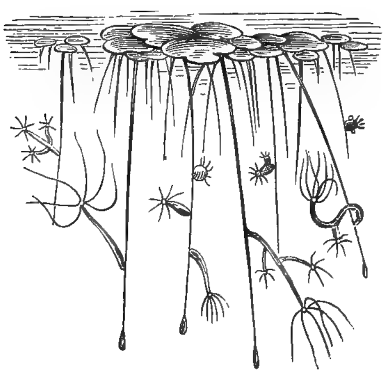


FIG. 18. Diagram showing hydrae growing on duckweed in a pond.

you see (Fig. 19) that the whole animal is made up of cells. These cells are arranged in two layers, an outer and an inner. In the outer layer, the cells, arranged like palisades, are columnar in shape; they are prolonged at their inner end into processes which run at right angles to the main bodies of the cells. The processes are highly contractile, while the outer parts of the cells are not contractile, but are irritable, and feel the contact of foreign bodies.

Embedded between the columnar cells, here and there occur oval sacs containing a coiled-up spring or barb surrounded with fluid. When these sacs are touched, the barbs are discharged so as to sting the hydra's prey. At the foot of the hydra the protoplasm of the outer layer of cells appears very granular. At this point the cells are glandular and capable of manufacturing and secreting a material by which the hydra can glue itself to a support. The inner layer of cells surrounds the gut. They are of two kinds, large and small. The large cells, which throw out

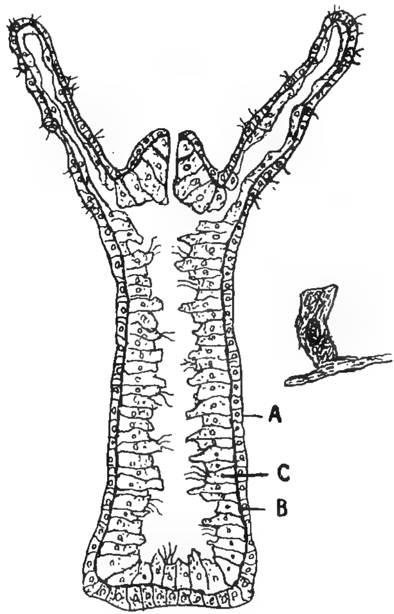


FIG. 19. Microscopical section of the body of a hydra. A. External sense-muscular cells. One of these is shown enlarged at the side. B. The layer formed by the muscle-processes of the external cells. C. Internal digestive and absorptive cells.

processes, are constantly undergoing change of form, and like an amoeba they flow round and engulf particles of food. This food they digest, and build into the living protoplasmic substance of the hydra.

The smaller cells are granular; they act as glands and *secrete* certain chemical substances known as ferments, which, passing into the gut, have power to break up food material and render it soluble and fit for absorption.

In the hydra we meet with differentiation of structure and function. A colony of cells live together; the outer ones feel, move, and catch prey for the inner cells; the inner ones digest, absorb, and feed both themselves and the outer cells. In the hydra there are differentiated cells, partly irritable and sensory, partly muscular and contractile, poison dart cells, secreting gland cells, and amoebiform eating cells. Lastly, certain cells become differentiated into germ or egg cells, which, escaping from the parent, multiply by division and grow into new colonies of cells. These are ultimately arranged in such a way as to form a new hydra. When a cell divides and becomes two cells, the nucleus and protoplasm, stimulated probably by some chemical change, undergo a most remarkable series of changes.

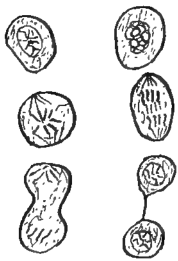


FIG. 20. Microscope, high power. A cell undergoing division, showing the separation of the nuclear network into loops; half of each loop goes to one daughter-cell and half to the other.

Division and growth of cells. In every nucleus there is a long twisted filament containing a material which stains intensely with many dyes, called *chromatin*. This filament parts into a definite number of loops or *chromosomes*, and each loop splits into two; half of each loop then travels off towards one end of the cell and half towards the

other. The loops thus doubled in number are guided by a spindle of fine fibres which run through the protoplasm.

So soon as the loops have been guided apart by the spindle fibres into two groups, the protoplasm of the cell divides and the loops then form a new twisted filament in the nucleus of each daughter-cell.

Among many unicellular organisms it is occasionally the habit for two individuals of the same species to come together, and, by coalescing, to form one. By this process of *conjugation* before division, the race is, in some unknown way, refreshed and strengthened. In higher organisms, whether plant or animal, the whole body does not divide, but special organs are differentiated which produce egg-cells. These cells, when fertilised by conjugation, develop into young organisms. Thus, in the case of clover, ova or egg-cells formed in the flowers are fertilised by pollen-cells brought by bees from other clover flowers. As a result of conjugation the clover seeds, when placed in suitable conditions of warmth and moisture, divide and form colonies of cells. These, impelled by some hidden force—and this is one of the greatest mysteries of life —slowly shape themselves, not into a new form, but into a clover closely resembling the parent plant.

To further the first stages of the growth of the ovum a store of food material is supplied in the seed by the parents. This food material is turned to account by man when he devours the eggs of birds, or makes flour from the seeds of peas and corn.

It is a noteworthy fact that after a hydra has been divided into pieces, each piece can, by the division and multiplication of cells, develop into a new hydra. In the higher animals this is not the case. If a tentacle of a hydra be cut off, the hydra will grow another, and the one that has been cut off will become a complete hydra in itself. A man, on the other hand, if he lose a limb cannot grow a

new one. The higher the development the more specialised are the cells of each organ, and the less are they capable of repairing or taking the place of the cells of any other organ. In animals higher than the polypes the differentiation of structure and function is carried to far greater lengths.

Differentiation of structure in man. In man there are myriads of cells allotted to each function; these cells are bound together to form tissues and organs. In each tissue or organ the cells have a special structure suitable for carrying out a special function.

In man there is an inner layer of cells lining the gut, and an outer layer coating the surface of the body. The gut becomes a long coiled canal and opens at the upper end by a mouth, at the lower end by an anus through which waste food material can be ejected. While the inner layer of cells is specialised to absorb the food, glandular cells are developed into special organs which pour their secretions through ducts into the gut. These secretions dissolve and digest the food.

The outer layer of cells forms a protective coat to the body. Groups of these cells are differentiated into horny material, others into hairs, and still others into glands which excrete sweat. Some of the outer cells become specialised into irritable cells, sensitive to contact with surrounding objects, to heat, and to cold. In certain places groups of outer cells become differentiated into special sense organs, eyes, ears, &c., sensitive to different forms of energy such as light and sound. The cells of all these sense organs are connected by long protoplasmic fibres or nerves to another set of cells, which are retired from the outside and lie within the body, forming a nerve centre. The nerves act like telegraph wires and convey messages from the sense-cells to the nerve-cells. The nerve-cells within thus become acquainted with what is happening to

the body without. While in the outer layer of the hydra the external part of each cell feels and the inner part contracts, in man vast numbers of special cells are differentiated into muscles which are so grouped and arranged that by their contraction different movements of the body are produced. In the hydra, the external part of each cell when irritated directly excites the internal muscular part to contract. In man, the sense organs when irritated send messages along the nerves to the nerve-centre, the nerve-centre at any one moment receives messages (sensations of light, sound, touch) of many kinds and from many parts of the body; thus it gains a complete knowledge of what is happening in the external world. Having gained this knowledge the nerve-centre despatches messages down other nerve fibres to the muscles. In this way the muscles are excited to contract, and the parts of the body are moved in an appropriate manner according to the will and judgment of the nerve centre.

At the same time nerve-fibres run from the gut and the glandular organs of the body to the nerve-centre, and acquaint it with their needs, exciting appetite and desire.

In order that the huge mass of protoplasm of which a man is composed may be supported and shaped into convenient and movable parts, groups of cells are differentiated into a hard framework—the bones. Other groups of cells become connective tissue, strong fibrous material which knits together the protoplasmic cells into organs, confines the organs within their proper spheres, and binds them to the bony framework.

It is obvious that in so large a mass as man, the food absorbed by the gut-cells could not reach the myriad cells of the other tissues and organs of the body without the help of some special contrivance.

The problem of food supply is solved by means of the circulation of the blood. The whole body is canalised by

minute tubes which run between the cells. Through these tubes the blood is driven by the ceaseless action of a pump —the heart. As the blood passes along the walls of the gut it is enriched by the food poured into it by the cells, whose duty it is to absorb. This enriched blood is circulated to all parts of the body.

The living cells likewise need oxygen; this too is supplied by the blood. From the mouth end of the gut, are developed great bags, the lungs, lined by a layer of cells. Into these bags, air is rhythmically drawn. To this air the blood, while circulating in the walls of the lungs, is exposed. There the blood absorbs oxygen and thence takes it to the tissues, while at the same time it renders up carbon dioxide gas, a waste product brought by the blood from the tissues. Beside carbon dioxide the tissues must be freed from other waste products, such as are formed when the energy of life is set free in protoplasm, water, salts, and simple nitrogenous bodies. These the blood collects and carries to special organs, the kidneys, whence is excreted urine.

The physiological teaching in the following passage is not entirely correct, yet herein the old French doctor, Rabelais, gives us a graphic picture of the differentiation of function and the give and take between the organs of the body. 'The intention of the founder of this microcosm is, to have a soul therein to be entertained, which is lodged there, as a guest with its host, that it may live there for a while. Life consisteth in blood; therefore the chiefest work of the microcosm, is, to be making blood continually. At this forge are exercised all the members of the body: none is exempted from labour; each operates apart and doth its proper office. And such is their hierarchy, that perpetually the one borrows from the other, the one lends the other, and the one is the other's debtor. The stuff and matter convenient, which nature giveth to be turned into blood, is bread and wine. All kind of nourishing

victual is understood to be comprehended in these two. To find out this meat and drink, to prepare and boil it, the hands are put to work, the feet do walk and bear up the whole bulk of the corporal mass; the eyes guide and conduct all; the appetite . . . giveth warning to shut in the food. The tongue doth make the first essay, and tastes it; the teeth do chew it, and the stomach doth receive, digest and chilify it; the meseraic veins suck out of it what is good and fit, leaving behind the excrements, which are, through special conduits for that purpose, voided by an expulsive faculty: thereafter it is carried to the liver, where it being changed again, it, by the virtue of that new transmutation, becomes blood. What joy, conjecture you, will then be found amongst those officers, when they see this rivulet of gold, which is their sole restorative? Then it is that every member doth prepare itself, and strive anew to purify and to refine this treasure. The kidneys draw that aquosity from thence which you call urine, and there send it away through the ureters to be slipt downwards; where, in a lower receptacle, and proper for it, to wit, the bladder, it is kept, and stayeth there until an opportunity to void it out in his due time. The spleen draweth from the blood its terrestrial part—viz., the grounds, lees, or thick substance settled in the bottom thereof, which you term melancholy. The bottle of the gall subtracts from thence all the superfluous choler; whence it is brought to another shop or workhouse to be yet purified and fined, that is the heart, which, by its agitation of diastolic and systolic motions, so neatly subtilizeth and inflames it, that . . . it is brought to perfection, and . . . is sent to all the members; each parcel of the body draws it then unto itself, and after its own fashion is cherished and alimented by it: feet, hands, thighs, arms, eyes, ears, back, breast, yea, all; and then it is that who before were lenders, now become debtors.'

CHAPTER XI

THE STRUCTURE OF MAN.

The head and body. The head consists of two parts; one part contains the brain—the cranium; the other surrounds the mouth, nose, and eyes—the face. The old Latin physician, Galen, 'allegeth that the head was made for the eyes; for nature might have placed our eyes in our knees or elbows, but having beforehand determined that the eyes should discover things from afar, she, for the better enabling them to execute their designed office, fixed them in the head (as on the top of a long pole), in the most prominent part of the body.'

The teeth. Before a looking-glass open your mouth and examine it. Inside you see the movable tongue, the upper and lower rows of teeth. Observe, in each row, the four *incisor* or cutting teeth in front; next to these, on either side, lies a single *canine* or dog tooth. These canines are seen when you raise the upper lip as in sneering.

In the dog, the long and pointed canines are used for fighting. Behind each canine lie two *bicuspids*. The crown of each of these is divided into two by a shallow depression, and the fang is double. Beyond the bicuspids lie on each side three *molars* or grinders, with broad crowns and two or three fangs. In the adult there are thirty-two teeth—

four incisors, two canines, four bicuspids, and six molars in each jaw. These are preceded in the child by twenty milk teeth—namely, four incisors, two canines, and four molars in each jaw.

The milk incisors are first cut about the eighth month of infant life. All the milk teeth are, as a rule, cut by the time the child is two years old. About the sixth year the first permanent teeth are cut, and the milk teeth drop out. At the age of five a child has all his milk teeth, while the growing buds of his permanent teeth are at the same time concealed within the substance of the jawbones. By the fifteenth year all the permanent teeth are cut except the third molars or wisdom teeth.

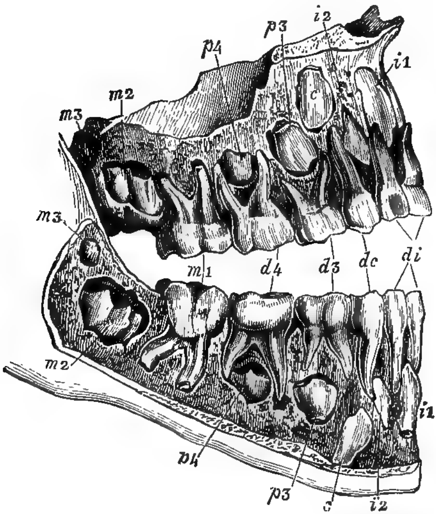


FIG. 21. Upper and lower jawbones of a child, sawn open to show the milk teeth and the germs of the permanent teeth. *di.* Milk incisors. *dc.* Milk canines. *d* 3, *d* 4. Milk molars. *m* 1, First molars. *i* 1 and *i* 2. Germs of permanent incisors. *c.* Canines; *p* 3 and *p* 4. Bicuspids. *m* 2 and *m* 3. Second and third molars.

The throat. At the back of the mouth you can see the pillars of the throat guarding the *fauces* or orifice to the *pharynx.* This orifice is bounded by the tongue below, the pillars of the throat (enclosing the tonsil) on either side, and the soft palate above, ending in the *uvula.* By

the descent of the soft palate, approximation of the pillars, and ascent of the base of the tongue, the orifice can be effectually closed.

The pharynx is a funnel-like cavity into which the nose and mouth open, and from the lower part of which the gullet and windpipe pass respectively to the stomach and lungs. You can see the hind wall of the pharynx if you open your mouth widely and say 'Ah.' Behind the pharynx there lies the vertebral column. Tobacco smoke drawn in at the mouth can be expelled through the nose. This proves that the nasal passages and the cavity of the mouth both communicate with the pharynx.

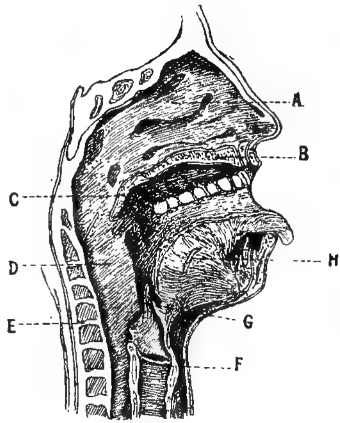


FIG. 22. Nose, mouth, pharynx, and larynx cut open lengthwise. A. Nose. B. Hard palate. C. Soft palate. D. Pharynx. E. Vertebrae. F Larynx. G. Epiglottis. H. Tongue.

If the soft palate be raised, as in swallowing, it forms a partition across the pharynx and blocks the communication between mouth and nose. While a man naturally eats and drinks with the mouth, he respires through the nose. But a man can breathe through his mouth, and it is possible to feed him by passing a tube through his nose to the top of the pharynx and pouring liquid down that. An india-rubber tube can be slipped to the back of the mouth and thence down the gullet into the stomach. By means of such a tube the stomach can be emptied in cases of poisoning. The gullet is about ten inches long. At the root of the tongue, and in front of the gullet, lies the opening into the windpipe. This

is guarded by a flap called the *epiglottis*. Acting something like a trap-door the epiglottis covers the windpipe during swallowing.

With the finger trace the hard bony outline of your lower jaw, both inside and outside the mouth. Place the finger in front of the ear and make biting movements. You can feel the movement in the hinge-joint of the jaw. Move the jaw from side to side as if grinding food. You not only feel but hear the end of the jawbone moving to and fro in the joint.

Place the fingers firstly on the cranium slightly in front of and above the ear, secondly on the cheek in front of the angle of the jaw, you will feel at these places muscles swelling under your fingers whenever you clench your teeth.

Trace out the ring of bone which encircles the eye, and forms the orbit or socket of that organ. From the ear there runs forward a strong projecting ridge of bone continued into the lower margin of the orbit. This is the cheek-bone. On pressing in your fingers below this, you can feel, through the soft pad of the cheek, the upper jawbone into which the upper row of teeth is inserted. Within the mouth you can trace a semicircular ridge of bone in which the upper teeth are fixed, and behind these teeth your finger passes into a bony vault, the hard palate. This forms the roof to the mouth, and the floor of the nose. In the upper part, the nose is rigid and bony. Here are the nasal bones. The lower part is soft and flexible; the two nostrils are separated by a partition. On drawing a deep breath the wings of the nose dilate.

The muscles of expression. In the figure on the frontispiece observe the muscles of the face. It is by means of these that the face assumes different expressions of pain, anger, amusement. There are rings of muscle round the

eye and mouth by means of which you can screw up either the eye or mouth. There is a muscle above the eye by which the skin of the forehead can be wrinkled, and several slips of muscle running to the angle of the mouth; by means of these the mouth can be distorted. By constant use of certain of these muscles of expression each face becomes set with wrinkles which betray the habitual emotions. It is by these lines, and not by bumps on the head, that the quacks known as 'phrenologists' read characters. On passing the hand over the cranium it is found to be a hard dome-shaped structure covered with the scalp.

The skull. Examine the figure of the skull, or still better, a skull itself, if you can gain access to a skeleton. The top of the cranium is roofed over by two flat *parietal* bones. These are joined together in the middle line. The forehead is formed by the *frontal* bone. The frontal bone below the forehead folds in so as to roof over the orbits and at the same time form the floor of the anterior part of the cranial cavity. At the back of the cranium is the *occipital* bone. This bone curves under so as to become part of the base of the skull, and is there pierced by a large hole (the *foramen magnum*) through which the brain is continuous with the spinal cord. On each side of this hole there is a smooth oval knob. These articulate with the top of the spine. On either side of the cranium, below the parietal bone, there lies the *temporal* bone. It is pierced by a hole which leads to the drum of the ear. The organ of hearing lies within the dense, hard substance of the temporal bone. This bone sends forward a bridge which joins the cheek-bone. The cheek-bone forms the outer side of the orbit. In front of the occipital bone the base of the skull is very irregular; it is here formed partly by the temporal, partly by the *sphenoid* bone. The

sphenoid sends from the base of the skull two wings of bone which enter into the construction of the side of the cranium. Within the cranium there is the great cavity which contains the brain. Many small holes pierce the base of the skull, and through these pass blood-vessels and nerves to and from the brain.

In the facial part of the skull there remains to be examined the upper and lower jawbones, the small nasal bones, and the orbit. The upper jawbones lie between the eyes and the mouth and at each side of the opening to the nose. In the mouth these bones form the sockets of the upper row of teeth, and with the *palate* bones complete the hard palate. On the inner side of each orbit there is a little flat bone, the *lachrymal.* This is marked with a groove, along which there passes the tear-duct, leading from the eye to the nose.

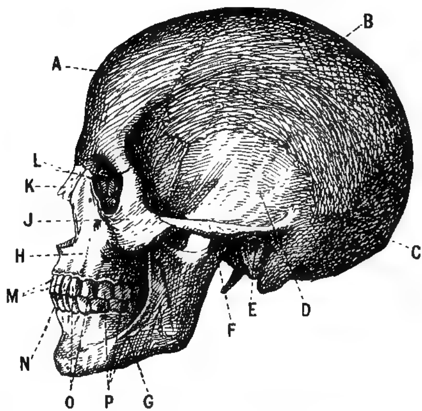


FIG. 23. Side view of the skull. A. Frontal bone. B. Parietal. C. Occipital. D. Temporal. E. Opening leading to the drum of the ear. F. Process of the temporal bone joining J, the cheek-bone. G. Lower jaw. H. Upper jaw. K. Nasal bone. L. Orbit. M. Upper incisors. N. Canine. O. Bicuspids. P. Molars.

Examine the anterior and posterior openings of the nose, the bony septum or *vomer* which separates the nose into two halves, the scroll-like *turbinate* bones which project on either side into the cavity of the nose.

The roof of the nose is formed by the *ethmoid* bone,

which also forms part of the inner wall of the orbit. The ethmoid separates the nose from the cranial cavity; it is pierced by many small holes through which pass the olfactory nerves to the brain. The lower jawbone is very strong and of an arched shape, bearing the sockets of the lower teeth. It is united by a joint to the temporal bone. The rest of the bones of the skull are joined together by irregular edges which fit into one another.

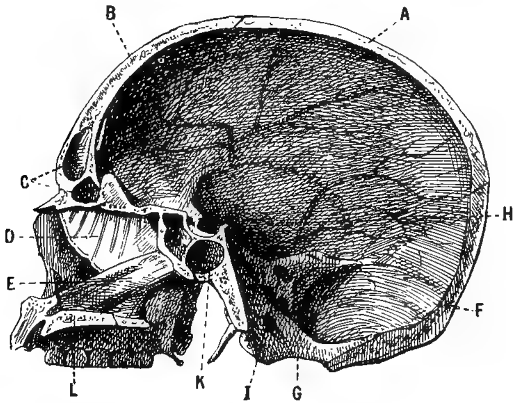


FIG. 24. Skull divided in half to show the cranial cavity in which the brain is lodged. A. Parietal bone. B. Frontal. C. Air-spaces in frontal bone. D. Ethmoid. E. Vomer. F. occipital. G. Margin of foramen magnum. H. Temporal bone. I. Hole through which auditory nerve passes to ear. K. Sphenoid (air-spaces). L. Upper jawbone.

Some of the bones of the skull, like the upper jaw and frontal bones, are not solid, but have within, in order to lighten their weight, large spaces full of air. Thus a projecting forehead may indicate a large brain, but it may equally well indicate a large air-space.

The skull is of great strength, in order that it may afford protection from external violence to the brain, the eye, and the ear; at the same time, it furnishes a powerful mill for tearing and grinding food. The head, by revolving upon the top of the spine, enables the eyes to sweep the horizon.

Man, by the assumption of the erect posture, is able to train his eyes and hands for the execution of skilled movements, and thus, by learning to walk on two legs instead of four, he has gained the mastery over all the animal world.

The trunk. Dissection of rabbit. Buy a wild rabbit from the poulterer's. Let it be one that has been freshly killed and not skinned. Compare the animal with yourself. It has a head consisting of face and cranium, neck, chest, abdomen, and four limbs. The fore-limbs correspond to your arms, the hind to your legs. Each limb is jointed in three places, corresponding in the one case to shoulder, elbow, and wrist joint; in the other to hip, knee, and ankle joint.

Run the fingers along the back of the animal; in the middle line there lies the bony spine. To the top of the spine the head is jointed in such a way that you can make it nod like your own head, backwards, forwards, or from side to side. The head can also be made to swivel round as upon a pivot. Compare your own head and spine with that of the rabbit. The chest of the rabbit is like your chest, strengthened on either side with ribs. These start from the spine and run round, to join a slender bone (the *sternum*) in front. Count the number of ribs on the rabbit and on yourself, and you will find them similar in number, twelve on each side. Below the sternum the ribs on either side become separated from each other, and you feel the soft abdomen or belly. Within the belly feel the outline of soft movable bodies.

Lay the rabbit on a board, belly downwards. Take a knife and divide the skin in a line starting from betwixt the eyes and continuing backwards over the cranium to the *occiput* (the protuberance at the back of the head). Thence continue the cut right down the middle of the back to the tail. Take hold of the divided skin on each side and draw it widely apart. There can now be seen the bony case of the cranium above, and below, a sheet of *white connective tissue* covering the *muscles* (flesh) which lie on each side along the spine.

The central nervous system. Take a very strong pair of pointed scissors. Push one point through the top of the

cranium, and cut away gradually the whole of the bony roof. A soft pinkish white mass, the great brain (*cerebrum*), is thus exposed to view. It is covered with a fibrous membrane, the *dura mater.* On removing this you will see in the middle line a fissure dividing the cerebrum into right and left *cerebral hemispheres.*

Cut away the muscles which run up the neck to the back of the head (the occiput) until you have exposed the bony spine.

Next scoop out the whole of the great brain with the handle of the knife, and examine the cranial cavity in which the brain lay, as it were, enclosed in a strong box. After cutting away the bone at the occiput, there becomes visible the small brain (*cerebellum*). Scoop out the cerebellum. The top of a canal which runs down the spine is now exposed. Insert one blade of the scissors within the *spinal canal*, and carefully cut away the roof of this canal. The white *spinal cord* which is continuous with the brain is then exposed. Pick up the spinal cord and pull gently on it with a pair of forceps, you will see on either side and at regular intervals little white cords (*nerves*), arising from the spinal cord and passing out through holes in the spine to the body.

Continue to remove the muscles from the spine and cut away the roof of the spinal canal, until you come to a place where the spinal cord ends low down in the back in a number of long nerves like a horse's tail.

The mouth, gullet, and windpipe. Now turn the rabbit over, belly uppermost, and nail its four legs to the board. Open its mouth; examine the cutting teeth—the incisors—in front, and the grinding teeth—the molars—behind. Look at the hard palate, which forms the roof of the mouth and divides it from the nose. Pull out the tongue, and examine not only that but the throat or pharynx at the back. Pass a flexible probe (a piece of wire will do) through one nostril, it will appear at the top of the pharynx. Pass a bent probe to the back of the throat; by a little gentle persuasion you can make it pass down the gullet or food pipe.

In the front of your neck you can feel a hard lump commonly known as Adam's apple. Examine its outline with your finger

and thumb. When you swallow this lump moves upwards. Adam's apple can be traced below into a hard cylindrical structure which passes down under the collar-bone into the chest. Squeeze this between finger and thumb, you experience a choking sensation. This is the wind-tube or *trachea*; Adam's apple, at the top, is the *larynx*. In the larynx a reed is set, which, when thrown into vibration by a blast of air, produces the voice. The food-tube or gullet lies behind the trachea, and so you cannot feel it.

In front of the rabbit's neck you can feel the gristly windpipe. Cut through the skin in the middle line from chin to sternum. Pull the skin apart and expose the neck-muscles. Separate these and you will see the windpipe marked with white rings. Catch hold of the windpipe betwixt finger and thumb; incise it. Pass a probe into the hole upwards, it appears in the mouth; downwards, it disappears into the chest. Slit up the windpipe till you come to the larynx; open and examine this. Notice the epiglottis at the root of the tongue. It is a flap guarding the orifice of the larynx.

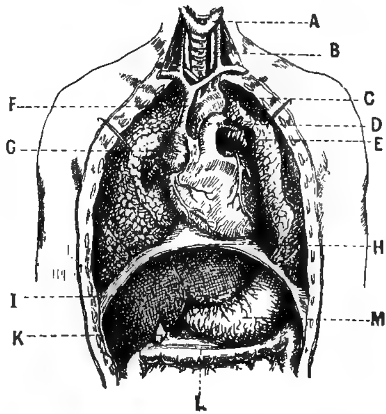


FIG. 25. The anterior wall of the thorax and abdomen (upper part) removed so as to show the viscera. A. Thyroid gland. B. Trachea with carotid artery, jugular vein and vagus nerves running on either side of it. C. Aorta. D. Pulmonary artery. E. Bronchus entering lung. F. Vena cava superior. G. Right auricle. H. Diaphragm. I. Liver. K. Gall bladder. L. Large intestine. M. Stomach.

The thorax. Carry the skin incision downwards in the mid-line to the lower end of the sternum. Divide the sternum with a pair of scissors from top to bottom, keeping the blade within the chest hard against the sternum, and cutting only with the outer blade. Thus you will avoid hurting structures which lie beneath. With the hands pull widely apart the two

halves of the sternum. The chest or *thorax* is now opened, the pink lungs exposed on either side. In the centre lies the heart within a bag; this is the heart-purse or *pericardium*. Pass a glass tube into the windpipe towards the lungs and blow, the lungs expand into large bags; cease blowing, they collapse. They are as distensile and elastic as a child's balloon.

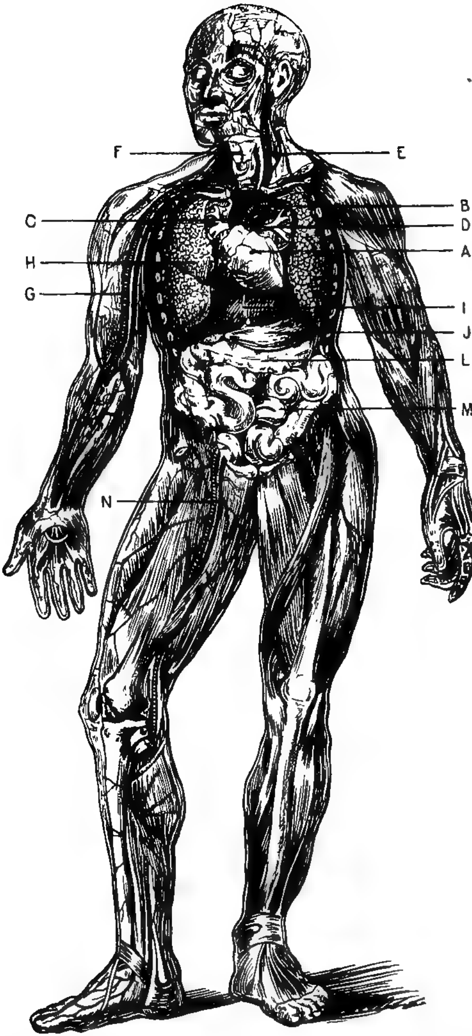
Slit up the heart-purse with the scissors and examine the heart. On the right side the heart is bluish black in colour, soft and flaccid. On the left side it is firmer in texture and redder in colour. Into the right side of the heart there pass three blue-black veins—the two[1] *superior vena cavae* and one *inferior vena cava*. You may trace veins downwards from the neck and from the forelimbs; these unite to form the superior venae cavae. From the abdomen there ascends a large vein, the inferior vena cava.

Out of the left side of the heart there passes an artery, the *aorta*. This curves round to form, near the top of the thorax, the arch of the aorta, and, after giving off some branches upwards to the neck, runs downwards along the prominence formed by the front of the spine. Here the aorta lies at the back of the thorax, and on the left side; in front of it there runs the gullet.

The floor of the thorax is formed by a dome-shaped muscular partition, the *diaphragm*, which separates the abdomen from the thorax. Its centre is transparent and fibrous. The vena cava inferior pierces this fibrous part on the right side. The aorta and gullet also pass through the diaphragm.

Cut across the windpipe in the neck. Take hold of the lower end with the hand and pull upon it, separating carefully with the knife any structures which hold it down. Continuing thus with a little care you can, after dividing the venae cavae and aorta, pull out the windpipe, lungs, and heart altogether. Place these organs in a basin of water, the lungs float. Trace the windpipe till it divides into two branches, one for each lung. Slit up the heart, on the right side blood comes out; wash it away under the tap; examine the cavity of the right heart. Observe the membranous flaps (*valves*) and strings of the valves within the right heart. Slit up the left heart and observe the valves and

[1] In man there is only one superior vena cava.



THE SKIN AND THE FRONT WALL OF THE CHEST AND ABDOMEN are removed to show the muscles, viscera, and some of the blood-vessels. A. Heart. B. Aorta. C. Vena cava superior. D. Pulmonary artery. The white tubes which the lines C, D cross are the pulmonary veins. E. Carotid artery and jugular vein. F. Larynx. G. Brachial artery and vein. H. Lung. I. Liver. J. Stomach. L. Large intestine. M. Small intestine. N. Femoral artery and vein. A coloured map of this figure is published by G. Gill, Warwick Lane.

valve-strings within it. Between the two sides of the heart there is a septum or partition.

Next examine the cavity of the thorax. Trace the ribs back to the spine, and observe the prominence formed by the spine at the back of the thorax. The ribs are mostly bone, but in front, where they join the sternum, they are made up of a more pliable substance which can be cut by the knife; this is gristle or *cartilage*. The ribs are joined together by muscle, and the inner lining of the thorax is smooth and glistening.

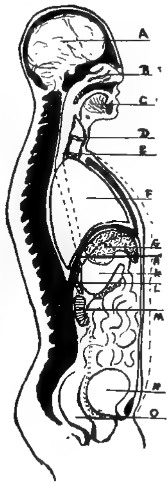


FIG. 26. Diagram of one half of the body (cut in two lengthwise). A. The brain in the cranial cavity. B. Nose. C. Tongue. D. Larynx. E. Gullet. F. Lung. G. Liver. H. Diaphragm. K. Stomach. L. Spleen. M. Kidney. N. Bladder. O. Rectum. The dotted line below the diaphragm indicates the descent of this partition in inspiration. The dotted line outside the body-wall indicates its enlargement during inspiration. The kidney is connected to the bladder by dotted lines which indicate the ureter. The shaded area just below the stomach is the pancreas.

The abdomen. Lying along the spine in front of the aorta is the gullet or food-tube. Open this and pass a probe upwards, the probe appears in the mouth. Turn the probe downwards, it passes into the stomach. Slit open the abdomen from top to bottom by an incision carried down the middle line. In addition make one or two transverse cuts, and turn the flaps of skin aside, so that the contents of the abdomen are completely exposed. Just below the diaphragm there lies the *liver*, a dark red mass, more or less divided into several lobes. Attached to the liver you may see the *gall bladder*, full of green gall or bile. Below the diaphragm, on the left side, and partly covered by the liver in front, lies the *stomach*, a large whitish bag, probably full of food. In this, feel for the probe which you passed down the gullet. Below the stomach lies the many-coiled *intestine*.

Pick up a loop of intestine; it is suspended by a glistening

transparent membrane, the *mesentery*, in which there run many blood-vessels. The blue veins pass to join the *portal vein*, which ends in the liver; the *mesenteric arteries* can be traced to their origin from the aorta. By pulling forward the intestine on the left side, there may be exposed, just below the stomach, a small red organ, the spleen. The *spleen* is also suspended by mesentery. Pull up a loop of intestine and tear through the mesentery with your fingers. Continue to pull and tear until you have unravelled and pulled out the whole of the intestine into one long tube. The last loop of intestine at the point where it joins the stomach is more firmly fixed by mesentery. This part is called the *duodenum*.

In the mesentery, attached to the duodenum, there lie scattered, thin, irregular-shaped masses of whitish colour. These form the *pancreas*. Both from the liver and from the pancreas there passes a fine duct which opens into the duodenum. Towards its lower end the intestine becomes much larger in girth and of a dark colour. This part contains faeces, and is called the *large intestine*. The large intestine ends in the *anus*. You can now trace a passage way right from the mouth to the anus, passing through pharynx, gullet, stomach, duodenum, small intestine, large intestine.

Make a small opening in the small intestine and insert a glass tube. By blowing into this you can distend the gut into a round tube. Slit open the intestine and examine the soft slimy inner wall; this is termed the *mucous membrane*. Open the stomach, turn out the half-digested food, and examine the mucous membrane. Open the large intestine in its upper part and near the anus; observe that the faeces are fluid above, solid below.

Having done with the intestines, examine the muscular wall of the abdomen, the diaphragm, and the prominence of the spine at the back. On the left side of this there lies the aorta, and on the right the vena cava inferior. The latter will contain blue blood. The diaphragm is attached to the spine by two muscular *pillars*, and between these the aorta passes downwards.

On each side of the spine there lies a round firm organ, the *kidney*. Just above the top margin of each kidney you may see a little organ, the *supra-renal* capsule. From each kidney there can be traced a fine white tube which runs down to the thin

transparent *bladder*. The bladder lies at the bottom of the abdomen in the pelvic basin, and may contain urine. A branch from the aorta enters the kidney (the *renal artery*), while the *renal vein* leaves it and passes into the vena cava inferior. Pull out a kidney, divide it in half with a knife, and observe the appearance of the inside.

Next examine the shape of the liver. Pull out this organ carefully, dividing the large veins which pass out from the liver and join the vena cava inferior where it pierces the diaphragm. Into the concave lower surface of the liver there pass both the portal vein and the *hepatic artery* (a branch of the aorta). From it there issues the *bile duct*. Cut open the liver and observe its appearance and consistency. Treat the spleen in the same manner.

Lastly, again carefully study the diaphragm, which is now left fully exposed as a partition between the thorax and abdomen. Tendinous and transparent in the centre, muscular and fleshy at the sides and back, it is pierced by the vena cava inferior on the right side, by the gullet on the left, while the aorta passes through the pillars of the diaphragm behind.

CHAPTER XII

THE SPINE, OR VERTEBRAL COLUMN, AND THORAX.

The vertebral column. The vertebral column consists of a number of separate bones or *vertebrae.* The vertebrae

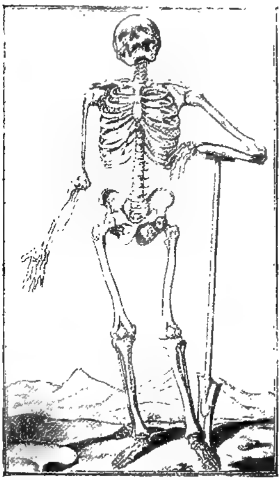
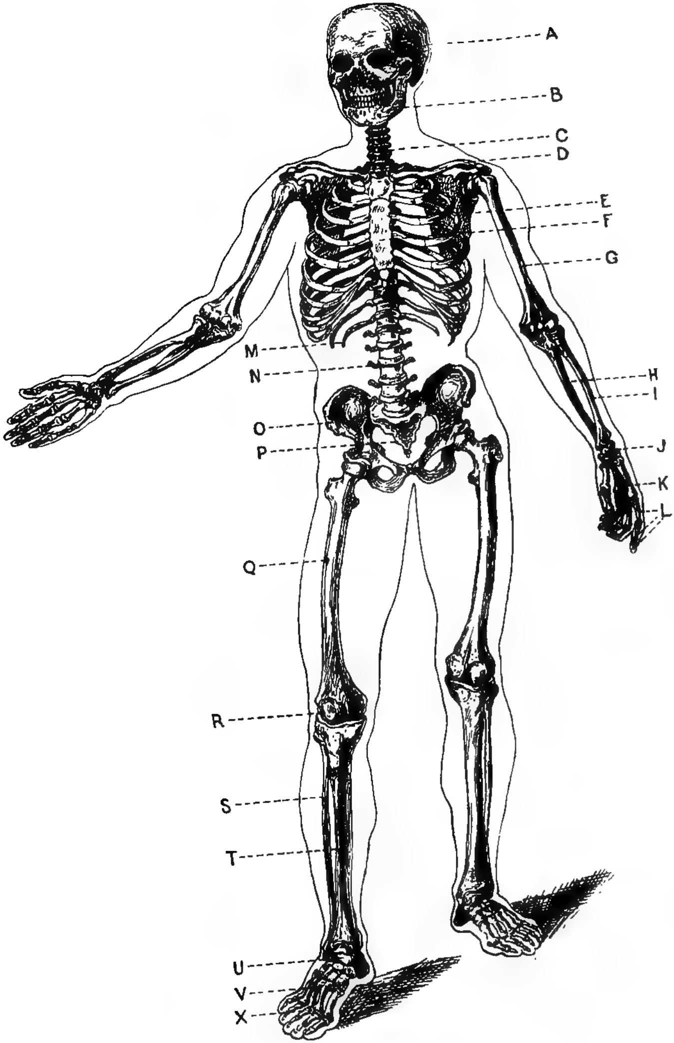


FIG. 27. Front view of skeleton.

FIG. 28. Back view of skeleton.

are originally thirty-three or four in number, but in the growth of the child, while five of the lower ones fuse together to form a broad curved bone known as the *sacrum,* the four



THE SKELETON. A. Skull. B. Lower jaw. C. Cervical vertebrae. D. Clavicle. E. Scapula. F. Sternum. G. Humerus. H. Ulna. I. Radius. J. Wrist or carpal bones. K. Metacarpal bones. L. Finger-bones. M. Floating ribs. N. Lumbar vertebrae. O. Hip-bone. P. Sacrum. Q. Femur. R. Patella. S. Fibula. T. Tibia. U. Tarsal or feet-bones. V. Metatarsal bones. X. Toe-bones.

lowest form a rudimentary tail called the *coccyx*. In the neck there are *seven cervical vertebrae*; at the back of the thorax *twelve dorsal vertebrae*, while at the back of the abdomen there are *five lumbar vertebrae*. The *sacrum* is on either side joined to the hip-bones, and thus forms the back of the *pelvis*. It is a wedge-shaped bone, the upper broad end of which articulates with the last lumbar vertebrae, the lower end with the tail-bones or *coccyx*. The spinal canal is continued down the sacrum. The arches and bodies of the five vertebrae which form the sacrum are fused together, bone taking the place of ligament. The coccyx can be felt as a bony projection at the extreme lower end of the spine.

Structure of the vertebrae. Each vertebra consists of the body, that is to say, a round mass of bone in front with an arch behind. From the body there spring the two pillars of the arches. These meet behind and thus form an arch, from the middle of which there projects backwards the spinous process. The arch and the body together enclose a ring. When the vertebrae are fitted together the rings form a continuous canal known as the *spinal or vertebral canal*. At the spot where the pillars of the arch spring from the body there projects outwards on either side a *transverse process*. The arches of the vertebrae articulate with each other by *articulating processes*. From each arch two of these project above and two below. The vertebrae are arranged one on the top of the other to form a column. Each is similar to the others in general form, but in order to carry the weight of the upper part of the body the lumbar vertebrae are larger and more massive than the others.

Intervertebral discs and ligaments. Between the bodies of the vertebrae there lie elastic cushions (*intervertebral discs*) of gristle or cartilage. These serve, not only to bind the vertebrae firmly together, but, acting like railway buffers, distribute shocks and jars.

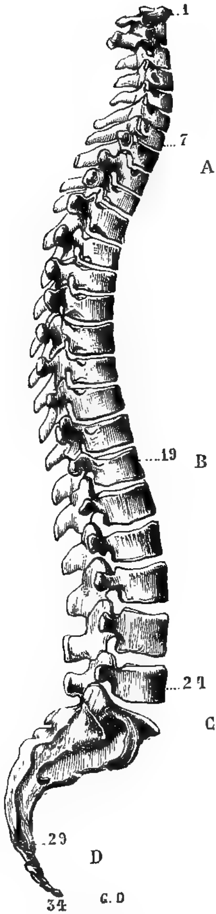


FIG. 29. The spinal column. 1–7. Cervical (7). 7–19. Thoracic (12). 19–24. Lumbar vertebrae (5). 24–29. Sacrum (= 5). 29–34. Coccyx (= 5). Notice the bends of the column.

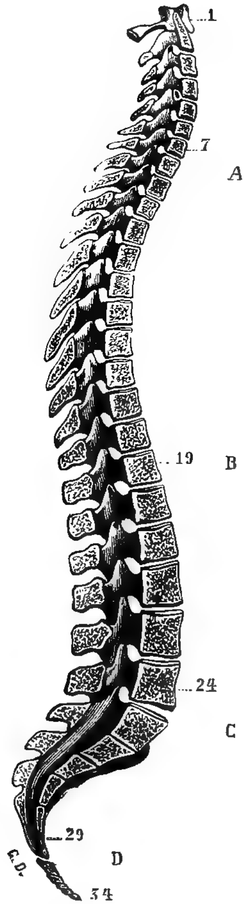


FIG. 30. Spinal column sawn asunder along its length, showing the canal which receives the spinal cord, and the holes between each vertebra through which pass out the nerves.

If you hammer a piece of lead, you can dent it with every stroke. Now place on the lead a piece of india-rubber and hammer that. You feel the elastic rebound of the rubber, and the lead is preserved from damage. A blow given through an elastic substance does not result in shattering or jolting.

The arches of the vertebrae are bound together by *elastic ligaments.* These fill up the gaps between the

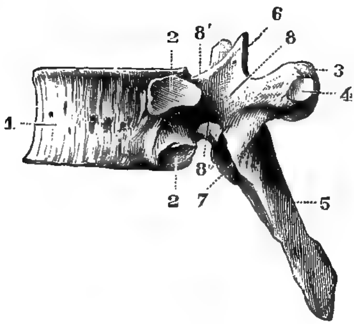


FIG. 31. Thoracic vertebra, side view. 1. Body. 2 and 4. Surfaces which articulate with ribs. 3. Transverse process. 5. Spinal process. 6 and 7. Surfaces which articulate with the next vertebra above and below.

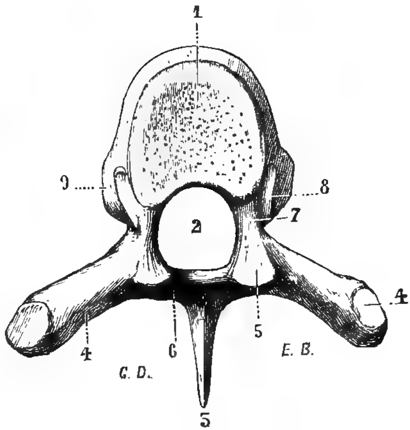


FIG. 32. Thoracic vertebra, top view. 1. Body. 2. Hole which forms part of vertebral canal. 3. Spinal process. 4. Transverse process. 5. Surface which articulates with next vertebra above. 8 and 4. Surfaces which articulate with a rib.

contiguous arches. The vertebrae are almost completely clothed with strong *fibrous ligaments.* The whole pile is thus combined into one strong column. A certain limited movement is at the same time possible in the spine, for each vertebra may move slightly from side to side and also twist round to a slight degree.

The spinous processes slope downwards, so that each process covers the arch of the vertebra beneath it. By running the finger down the mid-line of the back these

processes can be felt and the vertebrae thus counted. The vertebral column curves forwards in the neck, backwards in the thorax, forwards in the lumbar region, and backwards again in the sacral region. These curves give spring and elasticity to the column. If a man were to walk with a heavy weight on his head, the spinal column would slightly bend at each curve owing to the give of the elastic

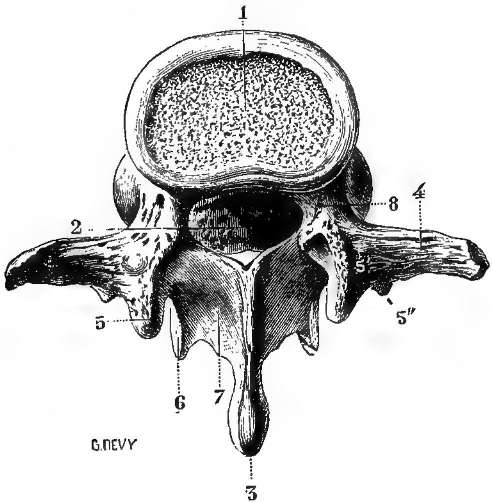


FIG. 33. Lumbar vertebra, top view. 1. Body. 2. Hole, part of vertebral canal. 3. Spinal, and 4. Transverse process. 5 and 6. Surfaces which articulate with next vertebra above and below.

cushions and ligaments. Thus the weight is supported by an elastic spring and jars are prevented.

The spinal column is constructed so as to be an immensely strong and elastic pillar of support to the head and trunk. At the same time, it protects from injury the spinal cord lying within the spinal canal. It is almost impossible to stab a knife through or between the vertebrae. Small openings are left between the vertebrae at the side

of the column. These openings, protected by the transverse processes, afford a passage for the exit of the nerves and the entrance of blood-vessels.

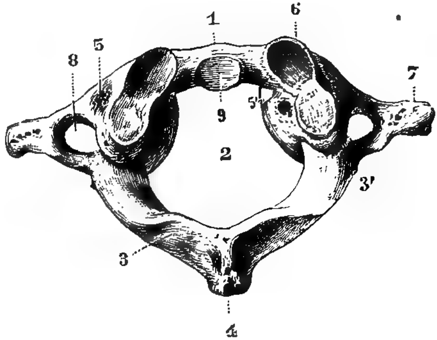


FIG. 34. Atlas vertebra, top view. 1. Body. 2 Hole, part of vertebral canal. 4. Spinal process. 6. Surfaces which articulate with the base of the skull. 7. Transverse process. 9. Surface articulating with the peg-shaped process of the axis.

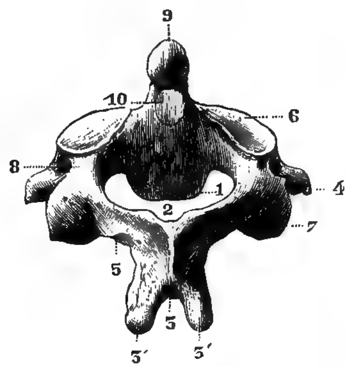


Fig. 35. The axis vertebra, top view. 1. Body. 2. Hole, part of vertebral canal. 3. Spinal process. 4. Transverse process. 6. Surfaces which articulate with atlas. 9. Odontoid or peg-shaped process.

The atlas and axis. The first (*atlas*) and second cervical vertebrae (*axis*) have certain peculiar features associated with the articulation of the head. The atlas is ring-shaped and has no proper body. Above, and on either side of the ring, there is a large smooth surface. On these surfaces the skull rests. The corresponding surfaces are to be found in the occipital bone at each side of the foramen magnum. The large ring of the atlas is separated by a very strong fibrous ligament into a smaller ring in front, and a larger ring behind. The latter forms part of the

spinal canal. The former encloses the peg-shaped process of the axis.

This process (the *odontoid process*) projects upwards from the body of the axis and is the peculiar feature of this vertebra. The atlas carries the head, and it is by means of the smooth articulatory surfaces of the atlas that the head can nod backwards and forwards. At the same time, the atlas, and the head with it, can turn round the odontoid process of the axis as it were upon a pivot. The extent of the movement is in each case controlled by strong check ligaments. From the spinous processes of the lower cervical vertebrae there runs a strong elastic ligament to be inserted into the occiput. In quadrupeds, the head is slung to the spine by this cord. In man, when erect, the weight of the head rests upon the spine, and this ligament is not therefore of much importance.

The muscles of the neck and back. Examine the neck-muscles which pass from the shoulder-girdle and from the spine to be attached to the head. Place the fingers behind one angle of the jaw and bend your head over to that side, you can feel one of these shorten and swell.

On each side of the spinous processes there are powerful muscles. These control the movement of the spine and help to maintain the body in the upright position.

The thoracic wall. The ribs. The thorax of the skeleton is like a basket or cage of bone. It is formed of the dorsal vertebrae behind, the sternum in front, and the twelve ribs. The sternum is a flat bone, about six inches long, and shaped like a dagger. The ribs articulate with the bodies and the transverse processes of the dorsal vertebrae, and then sweep round to articulate with the sternum. The front part of each rib near the sternum is formed of carti-

lage or gristle. Each rib as it sweeps round the thorax tends to slope downwards. Each of the first seven or *true ribs* articulates with the sternum, the next three are united to one common piece of cartilage which runs up to

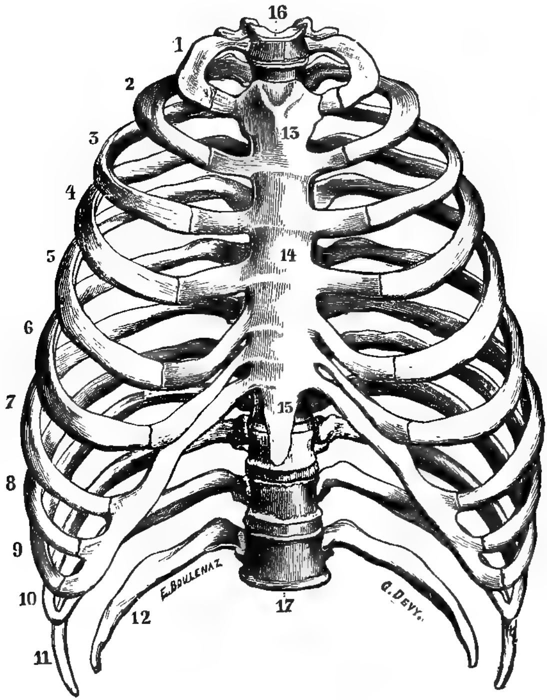


FIG. 36. The bony thorax. 1–12. Ribs. 13–15. Sternum. 16–17. The thoracic part of the spinal column (12 vertebrae).

join the sternum, the last two are quite unconnected in front and end in the muscular wall of the abdomen. The five ribs lowest in position are termed *false ribs*. Owing to the articulation of the ribs with the spine behind, and the elasticity of the rib-cartilages in front, the cage of the thorax

can to a certain extent be raised or lowered. Take a deep breath before a looking-glass and observe the elevation of the thorax. The ribs are joined together by thin sheets of muscle; the base of the thorax is, as you have seen in the rabbit, closed by the diaphragm. Powerful muscles run from the strong framework of the thorax to the spine, humerus, shoulder-bone, and skull. Other muscles run from the lower ribs to the hip-bone. These muscles can pull on the thorax, should the head and arm and hip be fixed, and act thus when a man is struggling for breath.

CHAPTER XIII

THE LIMBS.

The upper limb. The shoulder-girdle. In the front of the chest feel on yourself a longitudinal shallow depression, the floor of which is formed by the sternum, a flat bone. From the top of the sternum on either side trace the sinuous collar-bone running horizontally outwards and backwards to the shoulder. On the back of a friend feel the outline of the scapula or shoulder-bone ; this is broad and flat, terminating below in a blunt point, above rising into a horizontal ridge. The ridge joins the collar-bone at the external point of the shoulder. Hung beneath this part of the shoulder, the arm swings freely and in any direction. The scapula and collar-bone together form the shoulder-girdle.

The humerus. There is a long strong bone, the humerus, to be felt in the upper arm. The head of this bone is so jointed to the shoulder that the arm can swing freely backwards and forwards, inwards and outwards, round and round. Towards its lower end the humerus expands to form with the bones of the fore-arm a hinge joint—the elbow.

The radius and ulna. In the fore-arm there are two bones, the radius and the ulna. The head of the ulna

forms the bony point of the elbow; from thence trace its sinuous outline along the back of the fore-arm to the

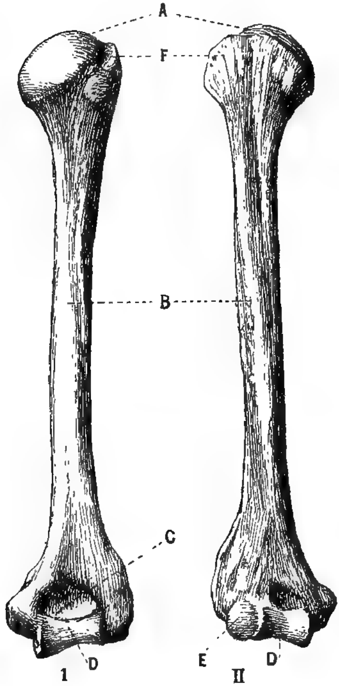


FIG. 37. I. Hind, and II. front view of humerus. A. Head of the bone which articulates with the scapula. B. Shaft. C. Cavity which receives the olecranon process (top) of the ulna. D. Surface which articulates with the ulna. E. Surface articulating with radius. F. Rough processes to which muscles are attached.

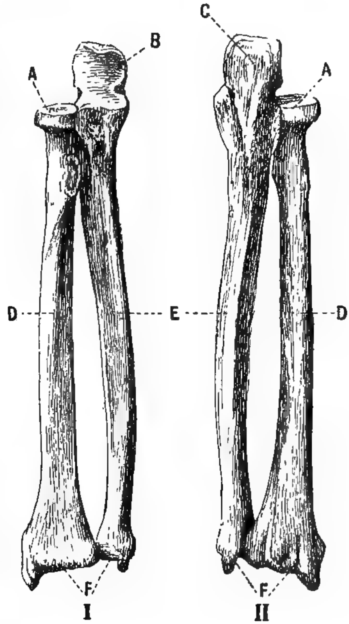


FIG. 38. I. Front, and II. back view of D, radius, and E, ulna. A and B Surfaces which articulate with humerus. C. Olecranon process of ulna. F. Surfaces which articulate with carpal bones of wrist.

wrist-joint. The radius can be felt in the lower part of fore-arm on the outer (thumb) side.

Bend up the fore-arm, and feel and see that the biceps, a great muscle on the front of the upper-arm,

swells and becomes hard. Raise the limb, a muscle swells at the top of the upper-arm. Keeping it raised, sweep it forwards and backwards; muscles in turn swell in front on the chest-wall, and behind the shoulder on the back.

The pronation and supination of the radius. Place the inner (little finger) side of your fore-arm on the table, and roll over the radius so that either the back or palm of the hand is exposed to view. During this movement the lower end of the radius rotates round the ulna, which remains stationary.

The carpus. At the wrist-joint there are a number of small bones, which cannot easily be felt, forming the carpus; these articulate with the ulna and radius. At the wrist-joint the hand can be flexed or extended, or moved from side to side.

The metacarpal bones. At the back of the hand and thumb trace short bones running from the carpus, one to each digit. These are the metacarpal bones. The metacarpal bone of the thumb, unlike the others, is freely movable, so that the thumb can be opened out from, or brought close to, the palm.

The phalanges. There are three little bones in each finger, the first one articulating with a metacarpal bone. The first phalanx articulates with a second, and the second, except in the case of the thumb, with a third. Thus each finger can be flexed or extended in three different segments.

Muscles of the arm. On extending the fingers there become visible underneath the skin, at the back of the

hand, cords (tendons) running to each finger. At the same time a muscle swells in the upper part of the back of the fore-arm. Muscles are seen to swell in the front of it on flexing the fingers and hand. At the same time two cords become visible in front of the lower part of the fore-arm. One of these tightens when the fingers are flexed,

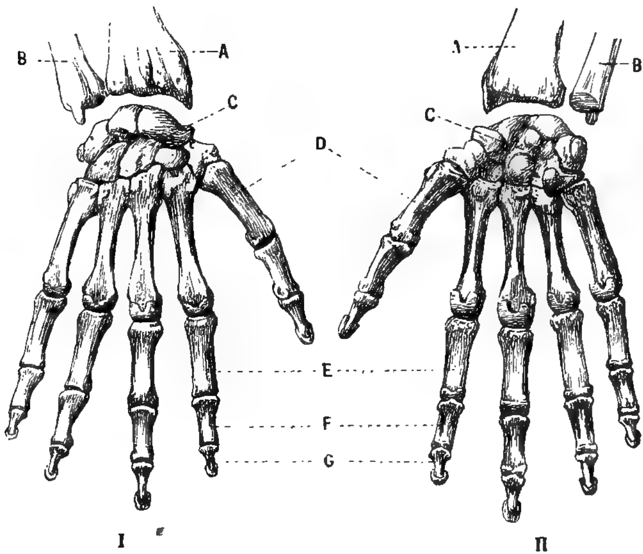


FIG. 39. I. Back surface, and II. palm surface of hand and wrist-bones. A. Radius. B. Ulna. C. Wrist or carpal bones. D. Metacarpal bones. E, F, G. First, second, and third finger-bones or phalanges.

the other when the hand is bent at the wrist-joint. While the bones of the upper and fore-arm are clothed with muscles, the hand and fingers are chiefly formed of skin, and bone, and tendon. The fingers are worked by means of the tendinous cords which run down from the muscles of the fore-arm and are attached to the bones of the fingers. These cords are confined in pulley-like grooves, which are

kept greased with fluid. Thus they not only work more easily, but transmit the pull of the muscles in definite directions. The ball of the thumb consists of short muscles, by means of which the tip of the thumb can be opposed to the finger-tips.

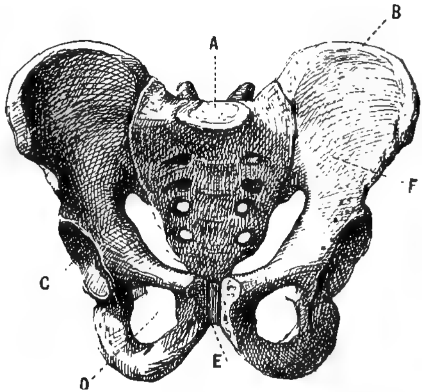


FIG. 40. The pelvis, consisting of A. The sacrum. B. crest of the hip-bones. C. The cavity (acetabulum) which receives the head of the femur. D. Hole which lightens the weight of the bone. E. Metal plate uniting the pubes. This is fibrous cartilage in life. F. Right hip-bone.

The lower limb. The pelvic girdle. The pelvic girdle is formed by the sacrum behind and the hip-bones on either side. These latter are large, flat, irregular-shaped bones which curve round and meet in front to form the joint of the pubis. The upper crest of the hip-bone can be traced as it runs forwards from the spine and forms the lower limit of the waist. It is by this ridge that a waist-band is prevented from slipping down. The hip-bones, together with the sacrum, form a basin-shaped cavity. On the sloping walls of this basin there rests the weight of the abdominal organs. In front the organs are confined by the elastic and muscular wall of the abdomen and by the skin.

On the outside of each hip-bone there is a round socket, within which fits the head of the thigh-bone. The weight of the body is transmitted directly from the spine through the sacrum and the hip-bones to the thigh-bones. The sacrum is not only wedged in between the hip-bones like

the key-stone of an arch, but these bones are united together to the lumbar vertebrae by immensely strong ligaments.

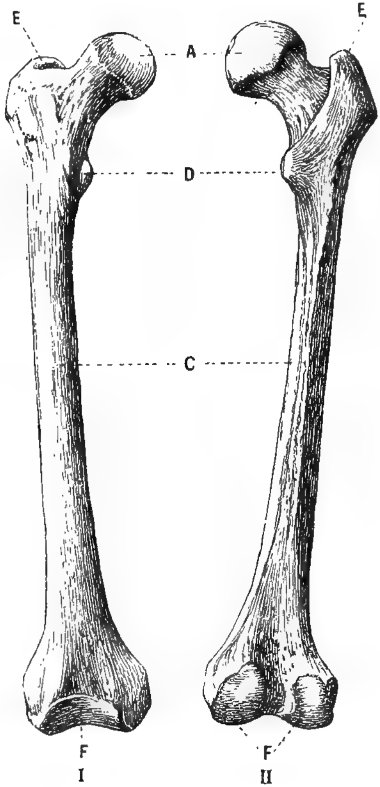


FIG. 41. I. Front, and II. hind view of femur. A. Head of the bone which articulates with the hip-bone. C. Shaft. D and E. Rough processes to which muscles are attached. F. Surface which articulates with tibia.

Thin sheets of muscles pass upwards from the crests of the hip-bones to join the ribs. These help to form the muscular wall of the abdomen.

The femur. The thigh-bone or *femur* is a very long and strong bone. It is formed of a cylindrical shaft on the top of which there is set a round head which fits into the socket of the hip-bone. The head is not set straight upon the top of the shaft, but is supported by a short neck which forms a blunt angle with the shaft. Where the neck joins the shaft there are two rough prominences of bone; to these muscles are attached. The roughness of a bone always indicates that muscles are there attached.

The lower end of the femur expands to form a broad

surface, which articulates with the tibia—the larger of the two leg-bones.

The head of the thigh-bone, resting in the socket of the hip-bone, forms a ball and socket joint (similar to a toy cup and ball). This kind of joint allows the leg to swing forwards and backwards, inwards and outwards, round in a circle. The bones are fastened together by strong check ligaments.

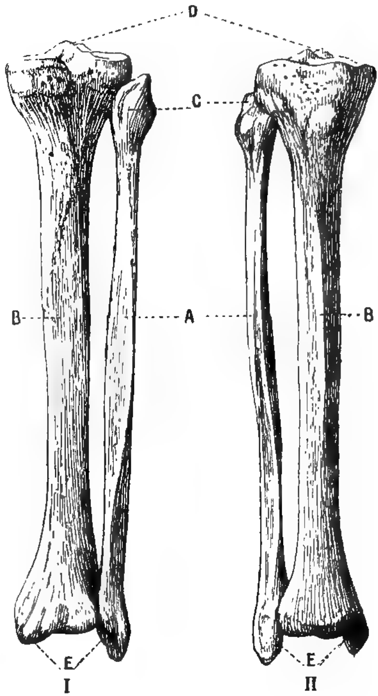


FIG. 42. I. Hind, and II. front view of B, tibia, and A, fibula. C. Head of the fibula articulating with tibia. D. Surface articulating with lower end of femur. E. Surfaces which articulate with astragalus.

The tibia and fibula and patella. In the leg there are two bones, the *tibia* and *fibula*. The tibia, or shin-bone, is long and strong and bears the weight of the body. The fibula, or splint-bone, is an equally long but much slenderer bone, and is attached to the tibia as a pin is to a brooch. At the top, the tibia presents a broad smooth surface, which articulates with the lower end of the femur, forming a hinge joint at the knee. In front of the knee is a small separate bone, the *patella* or knee-cap. Here, again, the bones are

fastened together by strong check ligaments which limit movement and prevent displacement. Both the tibia and fibula expand below into prominences of bone which can be felt on either side of the ankle-joint. Between these there is an articulating surface into which the top of a foot-bone called the *astragalus* fits, thus forming the ankle-joint. As the prominences are placed on either side of the joint they prevent the displacement of the astragalus. The ankle-joint is a hinge joint, and is surrounded and secured by strong ligaments.

The tarsal, metatarsal, and phalangeal bones. The foot consists of a set of tarsal, metatarsal, and phalangeal bones corresponding to the carpal, metacarpal, and phalangeal bones of the hand. Similarly the tibia and fibula correspond to the ulna and radius, the femur to the humerus, and the pelvic girdle to the shoulder-girdle. The two limbs, although differing in many points, are built on the same general plan, the one being adapted for grasping and the other for walking.

The tarsus consists of the *os calcis* or heel-bone, the astragalus, which rests on the top of the heel-bone and supports the tibia, and also of five smaller bones. These last form the connecting link between the astragalus and heel-bone and the metatarsal bones. The metatarsal bones are five short cylindrical bones, each articulating with the first phalanx of a toe. Each toe, except the great toe, has three short phalanges. The great toe has two. The bones of the foot, built in the form of an arch, afford a broad, strong surface for the support of the weight of the body. The balls of the toes and the heel form the piers, while the astragalus is the key-stone of the arch. This arch gives spring and elasticity to the feet, and is of the utmost importance in preventing jars and jolts. A person with a flat foot, i.e. with an insufficient arch, suffers

from pain, and requires the support of an artificial arch placed in his boot.

The bones of the foot are bound together with strong ligaments which allow very little movement. The metatarsal bone of the big toe in man is fixed, and in this respect differs from the thumb. In monkeys, on the other hand, the big toe can be used like the thumb in clasping boughs

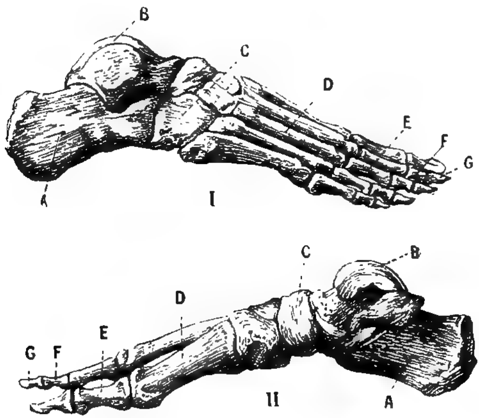


FIG. 43. Outer, and II. inner view of feet-bones. A. Heel-bone. B. Surface on astragalus which articulates with leg-bones. C. Tarsal; D. Metatarsal bones. E, F, G. First, second, and third toe-bones or phalanges.

and so on. Man uses his big toe to propel his body in walking. He does not need to cling to trees by his toes.

The muscles of the lower limb. Examine your own thigh. It is clothed with muscles. The thigh-bone can be felt on the outside in the upper part. From the hip-bone and sacrum behind there pass great muscles to the top of the femur. These on each side form the fleshy swellings of the buttocks and afford us the elastic cushions on which we comfortably sit. When in action, these muscles bring the thighs in a straight line with the

back. Down the front of the thigh there run muscles from the hip-bone to the femur and tibia. These produce flexion of the thigh at the hip-joint and extension of the leg at the knee-joint. Bend the thigh up to the body and feel the swelling of these muscles. Next straighten your leg at the knee-joint and feel the tightening of a broad cord just above the patella. Note that the above muscles can be used either to move the body to or from the limb, or the limb to or from the body. Other muscles are so arranged as to pull the legs apart or bring them near together. At the back of the thigh there are powerful muscles named the hamstrings; these flex the leg at the knee-joint. At the back of the leg, below the knee, the swelling of the calf-muscles can be felt. These pull by means of a tendinous cord on to the heel-bone. Other muscles of the leg send tendinous cords to run along the upper and lower surface of the foot to be inserted into the bones of the foot and toes, and by their means the foot and the toes are flexed or extended. Along the front and inner side of the leg the tibia can be felt, for there it is covered only by skin.

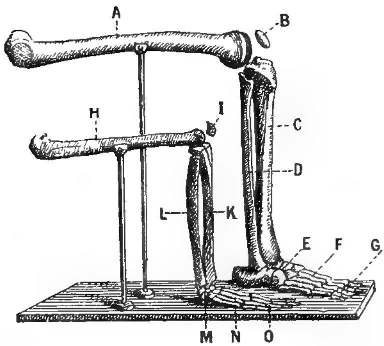


FIG. 44. Figure showing that leg and arm bones are formed on the same plan. A. Femur, and H humerus. B. Patella or knee-cap bone, and I olecranon process of ulna detached. C. Tibia, and K ulna. D. Fibula, and L radius. E. Tarsal, and M carpal bones. F. Metatarsal, and N metacarpal bones. G and O. Phalanges of toes and fingers.

The foot is chiefly made up of skin and bone.

Place a foot in water and then stand on a dry board. The imprint on the board will show how much of the

foot touches the ground, and thus the extent of the arch. A flat foot gives too wide an imprint.

Table of the Skeleton.

Cranium. Eight bones.

One frontal bone.	One occipital bone.
Two parietal bones.	One sphenoid bone.
Two temporal bones.	One ethmoid bone.

Face. Fourteen bones.

Two nasal bones.
Two spongy (turbinate) bones } within the nose.
One vomer (bony septum) of nose } within the nose.
Two lachrymal bones.
Two cheek-bones.
Two upper jawbones.
Two palate bones.
One lower jawbone.

Upper limb. Thirty-two bones.	**Lower limb.** Thirty-one bones.
Shoulder-girdle. Scapula and collar-bone.	*Pelvic girdle.* Hip-bone.
Upper-arm. Humerus.	*Thigh.* Femur.
Fore-arm. Radius and ulna.	*Knee-cap* or patella.
Wrist and Hand. Eight carpal and five metacarpal bones.	*Leg.* Tibia and fibula.
Fingers. Three phalanges in each = 12.	*Ankle and Foot.* Seven tarsal and five metatarsal bones.
Thumb. Two phalanges.	*Toes.* Three phalanges in each = 12.
	Big toe. Two phalanges.

Neck. Seven cervical vertebrae.

Thorax. Thirty-seven bones.

Twelve dorsal vertebrae.
Twenty-four ribs.
One sternum.

Loins. Five lumbar vertebrae.

Pelvic basin.

One sacrum, one coccyx.
Two hip-bones.

Vertebral column.

Seven cervical vertebrae.
Twelve dorsal vertebrae.
Five lumbar vertebrae.
Sacrum.
Coccyx.

There are in all about 206 separate bones in the adult skeleton; the number varies slightly, as with advancing age some bones unite with others.

CHAPTER XIV

JOINTS AND LIGAMENTS.

JOINTS between bones fall into two great classes, the *perfect* or movable and the *imperfect* or practically immovable. The skull-bones are locked immovably together by their serrated edges. The cartilaginous discs between the vertebrae allow of very little movement, and form imperfect joints. Such joints as the hip, knee, or shoulder, are perfectly jointed, and there great freedom of movement is allowed. In imperfect joints the bones are united by gristle, and are strapped tightly together by ligaments. Ligaments are tough bands formed of a white flexible material, fibrous in nature and inextensile. In the perfect joints the bones come in contact with smooth polished surfaces. These surfaces are covered with a thin layer of gristle or cartilage. Each joint is enclosed by a loose bag—the capsule—formed of a sheet of fibrous tissue which runs from one bone to the other. The joints are also supplied with strong ligaments so arranged as to check excessive movement. Movement is not only limited by ligaments, but also by bony prominences which lock the bones within the joint. The capsule is lined within by a smooth glistening membrane; from this membrane there is secreted a small quantity of *synovial* fluid which keeps the joint moist and acts as a lubricant.

Buy a sheep's trotter and open the joints and examine their general structure.

Joints are of various kinds.

Hinge joints. This type of joint allows the parts to open and shut like the lid of a door or box. The elbow-joint is a good example; you can only flex or extend it. The wrist, knee, and ankle joints are less perfect examples because the bones there may also move slightly from side to side. The lower jaw is fixed to the skull mainly by a hinge joint, but this is so constructed as to allow a certain amount of gliding movement.

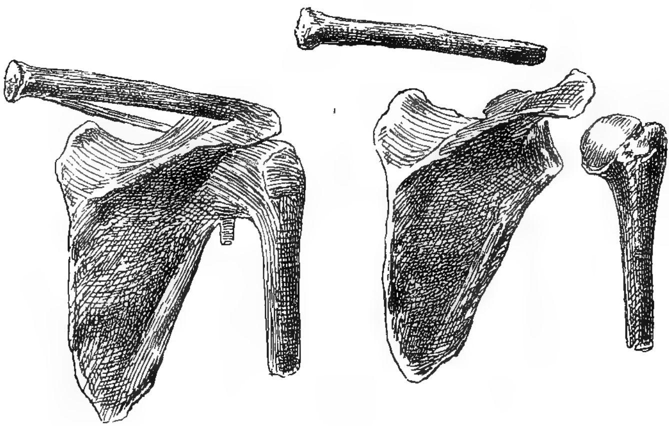


FIG. 45. Shoulder-joint, collar-bone, shoulder-blade, and upper end of humerus shown separate and bound together by ligaments.

Gliding joints exist between the carpal and tarsal bones. The ends of the bones have smooth flat surfaces covered with cartilage and moistened with synovial fluid. Between the bones only a very limited amount of slipping movement is permitted, for the bones are bound tightly together by the strong ligaments which surround the joints.

Ball and socket joints exist at the hip, at the shoulder, and between the metacarpal and first phalangeal bones. These joints allow movements in all directions. The

limbs can be swung round in a circle, or rotated, i. e. twisted round in the joint.

Sit in a chair, extend one leg, and, placing the heel on the floor, roll the foot. You will feel the thigh-bone rotating in the upper part of the thigh. Note that while the thigh-bone moves through a small space, that described by the tips of the toes is much larger.

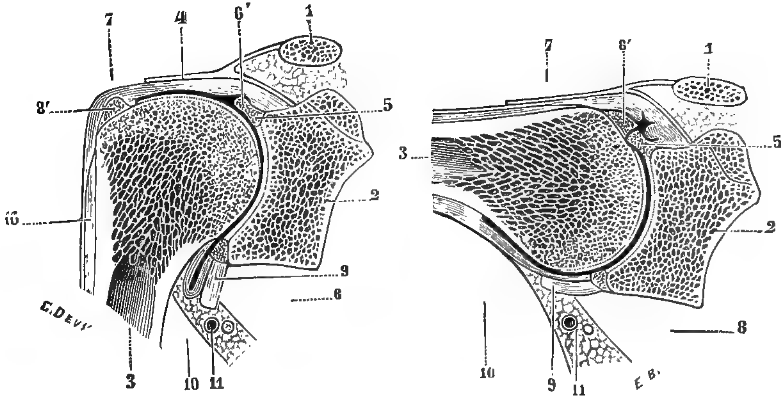


FIG. 46. The shoulder-joint sawn in twain. In the left figure the humerus hangs down. In the right, it is represented as stretched out. The big head of the humerus (3) plays in the shallow cup of the scapula (2).

Pivot joints, allowing rotation only, like the swivel of a dogchain, exist between the atlas and axis, the radius and ulna. The upper end of the radius acts as a swivel to the ulna, while the odontoid process of the axis is the swivel of the atlas.

EXAMPLES OF JOINTS.

The shoulder-joint. The humerus, ending in a smooth round head, fits into a shallow cup-like cavity in the scapula. This bony cup, surrounded by a ring of fibro-cartilage, is somewhat deepened thereby. The capsule attached above to this ring, and below to the neck of the humerus, com-

pletely encloses the joint in a loose bag. Owing to this arrangement, movement of the head of the humerus is freely permitted. Strap-like ligaments fasten the humerus securely to the scapula, and the muscles passing over the shoulder-joint help to maintain the bone in its place. By means of the muscles acting on the shoulder-joint the arm can be raised, lowered, swung forwards and backwards, rotated in the manner of a pivot, and swung round in a circle. When the arm is raised into line with the shoulder the humerus comes in contact with the overhanging projection formed by the union of the collar-bone and the acromial process of the scapula. If the arm be raised still further, the scapula moves also.

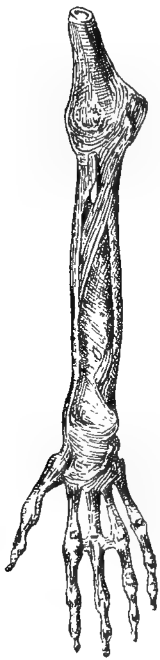


FIG. 47. Elbow and wrist joints shown strapped by ligaments.

Determine this fact on the back of a friend, and mark out the position of the muscles which contract during the movement.

The elbow-joint. This is a hinge joint. At its lower end the humerus expanding becomes broadened from side to side, ending in a rounded, smooth surface. The latter is divided into two parts by a ridge; on the inner side the ulna articulates, on the outer side the radius. The ulna behind forms the prominent point of the elbow, and in front this prominence of bone is deeply notched. Into the notch, which is lined with cartilage, the smooth cylindrical surface of the humerus exactly fits.

The small round head of the radius presents a cup-like

surface which plays against the outer part of the articular surface of the humerus. The thickened edge of the cup is also smooth and covered with cartilage. This edge fits into a shallow depression on the outer surface of the ulna. The head of the radius is surrounded and fastened to the ulna by a ring of fibrous tissue. The lower end of the ulna is small and rounded, while that of the radius is wide and almost excludes the ulna from the wrist-joint. The radius, by means of its lower surface, articulates with the bones of the carpus or wrist, and thus carries the hand. On the inner side of this end of the radius is a shallow concavity into which fits the small and rounded end of the ulna. The conditions at the upper and lower end of the radius and ulna are thus almost exactly reversed.

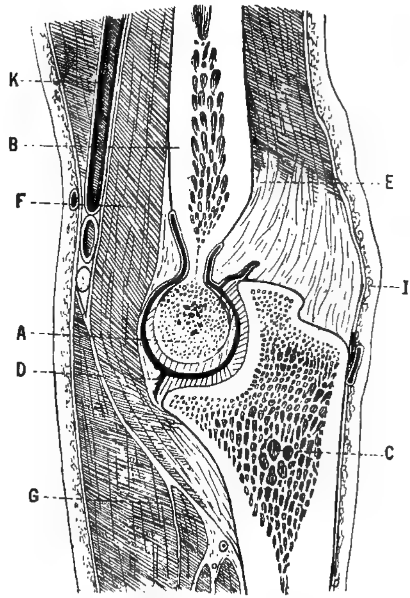


FIG. 48. Elbow-joint sawn in two lengthwise. A. Lower articular end of humerus fitting into cup-shaped cavity of C, the ulna. D. Cartilage covering articular surfaces. B. Shaft of humerus. E, F, G. Muscles. I. Skin. K. Blood-vessels.

At the elbow the bones are enclosed in a capsule which is strengthened by bands of ligament. Owing to the shape of the elbow-joint, simple hinge movements alone are permitted here. It is owing to the peculiar articulation of the radius with the carpus and the ulna that the hand can be rolled

over, while the ulna remains fixed. The radius, carrying the hand with it, rotates round the ulna below, while above, by means of its pivot joint, the head of this bone turns on the smooth articular surface of the humerus.

Lay your hand on the table. When the palm of the hand is upwards, the position is termed one of *supination*; when downwards, one of *pronation*.

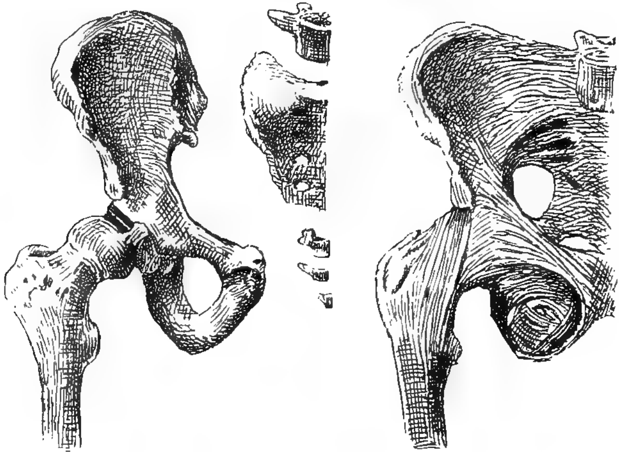


FIG. 49. Hip-joint. Thigh-bone, hip-bone, and half the sacrum shown separate and bound together by ligaments.

The hip-joint. In man, the round head of the femur fits into the deep, cup-like cavity (acetabulum) of the hip-bone. The capsule is fastened below to the neck of the femur, above to the edge of the cup. From the head of the femur there passes a curious *round ligament*, to be inserted in the bottom of the cup. This is lax enough to allow of free movement; it does not possess great strength, and is of little importance. Crossing the front of the joint is a very strong band of fibrous tissue running from the hip-bone to

the neck of the femur. This ligament not only prevents the displacement of the head of the bone, but helps to support the body in the erect posture; for when, by the action of the muscles, the femur is fixed in the extended position, the ligament tightens and stops the body from falling backwards.

The same movements are possible here as in the shoulder-joint, but to a more limited extent, for the socket is deeper, and the capsule tighter. Moreover, the hip-bone is firmly fixed to the spine, while the scapula is free to move.

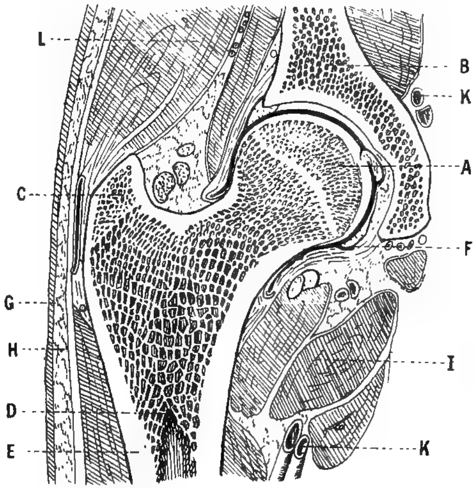


FIG. 50. Hip-joint sawn in two, lengthwise. A. Head of femur fitting into cup-shaped cavity of B, the hip-bone. C. Process of femur to which muscles, L, are attached. D. Marrow cavity, and E, compact bone of shaft of femur. F. Cavity of joint. G. Skin. H. Fat. I. Muscles, and K, blood-vessels on inside of thigh.

The knee-joint. The fibula or splint-bone does not enter into this joint, but is fastened to the tibia on its outer side just below the knee.

The femur, broadening at its lower end, swells into two large and smooth articular surfaces. These are continuous in front, while behind they are separated by a groove or depression. The upper end of the tibia forms a broad smooth platform on which the femur rests. There are two shallow saucer-like articular surfaces on the top of the tibia, deep-

ened on the outside by semicircular bands of fibro-cartilage, and separated from each other by a roughness, whence the *crucial* check ligaments arise. These latter are strong bands which cross each other and pass to be inserted into the groove between the articular surfaces of the femur. They hold the bones together, and, by tightening, prevent over-extension. It is owing to the restraining influence of these ligaments that the leg, when brought by the muscles into a straight line with the femur, cannot be forced forward beyond this line. In standing erect, these ligaments are tightened, and thus the leg is kept in position without much muscular effort.

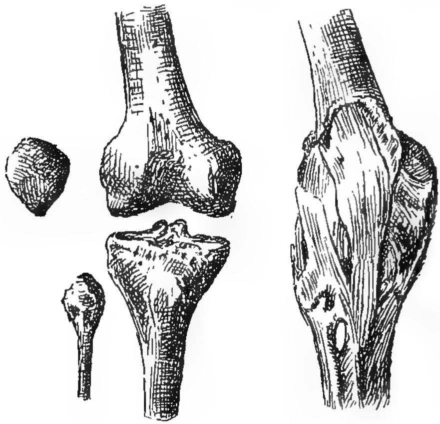


FIG. 51. Knee-joint. Lower end of femur, upper ends of tibia and fibula and patella shown separate and bound together by ligaments.

The front part of each articular surface of the femur rests upon the tibia when the leg is straightened. On the other hand, in the bent position, the posterior part of these surfaces alone come in contact. Thus the articular surfaces of the femur are larger than those of the tibia, and different portions of the former revolve into position on the latter during the hinge movements which are possible in this joint. The capsule enclosing the joint is strengthened by a strong fibrous band in front of the joint. The fibrous band is the tendon of the extensor muscle of the thigh which strengthens the leg. Attached

to this band is the knee-cap or patella, the inner surface of which is smoothened and covered with cartilage so as to play upon the front part of the articular surface of the femur. A fibrous band connects the lower end of the patella to the tibia. The knee-joint is strengthened

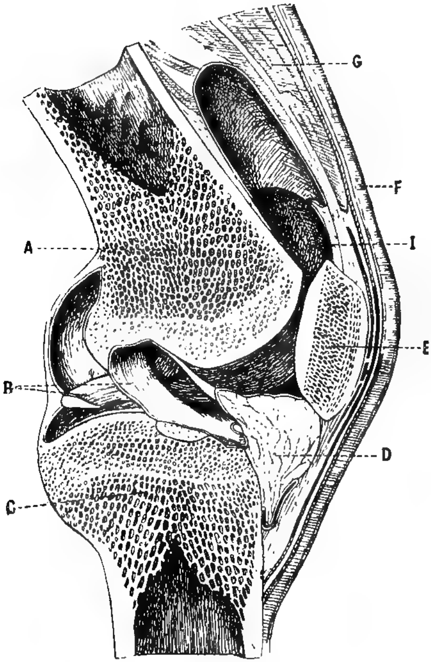


FIG. 52. The knee-joint, divided lengthwise. A. End of the femur. B. Crossed ligaments uniting femur to C, the tibia. D. Pad of fat. E. Knee-cap or patella. F. Skin. G. Muscles. I. Articular surface of femur covered with cartilage.

behind and at the sides by band-like ligaments. To prevent friction, when kneeling upon the ground, a small fibrous bag moistened with synovial fluid lies between the skin and the patella. This may become swollen in weakly persons from overuse, forming a swelling known as housemaid's knee. Such bags are found between

skin and bone wherever the parts are exposed to much friction.

The ankle-joint. The prominences on either side of the ankle-joint are formed by the lower end of the tibia and fibula. The upper surface of the astragalus fits in between these prominences, forming with them a joint like a carpenter's mortice. The bones are strapped together by strong ligaments, and here only hinge movements are possible. Behind the joint is the *tendo Achilles,* the tendon of the powerful calf-muscles. This is inserted into the back of the heel-bone. A man rises on tiptoe when this tendon, transmitting the pull of the calf-muscles, tightens and raises the heel. During this action the toes are pressed against the ground, but if the toes be placed on the pedal of a bicycle, the force of the calf-muscles will be transmitted thereto, and the pedal will turn.

FIG. 53. Ankle-joint and upper surface of feet-bones shown strapped together by ligaments.

CHAPTER XV

THE STRUCTURE OF THE SUPPORTING TISSUES.

IF a number of fertilized eggs be placed under a broody hen, and at the end of each hour the eggs be taken out successively and the shell picked off, the growth of the ovum can be examined under the microscope. The ovum, originally a single cell, divides into two, these into four, eight, sixteen, and so on, until a little cluster of cells appear, lying as a minute speck on the surface of the food material or yolk, which forms the mass of the egg. As the embryo grows, and the cells develop here into blood, heart, brain, and nerves, there into muscle, intestine, and glands, certain cells are set apart to produce fibrous tissue, cartilage, or bone, by which the framework of the body and its organs are moulded and held together. So the wonderful growth of the embryo proceeds, until at the end of three weeks' incubation the food material has vanished and a chick steps from the shell.

Connective tissue. In the leg of a dead rabbit or mouse, between the skin and the muscle, ensheathing the muscles and binding them to the skin, are membranes of connective tissue looking something like the fluff of cotton-wool. Pick up a fragment of such, snip it off with scissors, and by means of a pair of needles spread it out into a thin sheet on a glass slide. In the middle of the sheet place a drop of salt solution (0·8 %), cover with a glass cover-slip, and examine under the microscope (high power).

You will now see wavy bundles of fibrils, white in colour,

running across the membrane in all directions. Across these bundles run exceedingly fine straight fibres, which branch and coil up like a broken spring. These fibres are elastic, while the white bundles are inelastic but very strong. A drop of weak acid, such as vinegar (acetic acid), causes the white bundles to become swollen and transparent, and throws up the elastic fibres more clearly into view.

Between and upon the fibres there lie cells, some of which are flattened and branched, others are round and granular. The cells may be brought more strongly into view by placing a drop of dilute dye[1], such as red ink, or a solution of haematoxylin, upon a preparation of connective tissue.

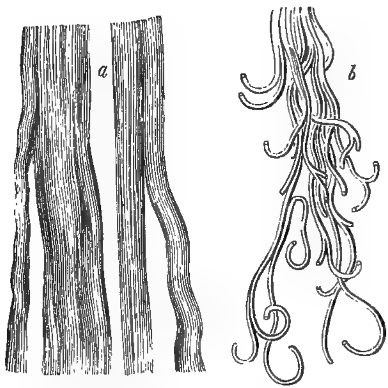


FIG. 54. Microscope, high power. a. White fibrous tissue. b. Yellow elastic tissue.

In life, this tissue is pervaded with fluid (lymph) which soaks out from the blood-vessels.

Connective tissue is a loose but strong structure which within certain limits allows the skin to move over the muscles, or the muscles under the skin. In the glandular organs, such as the liver, kidney, &c., it binds the groups of gland cells together, and at the same time permits these organs to swell or diminish in size.

Adipose tissue. The connective tissue under the skin in most places becomes filled with fat; it is then called fatty

[1] Many different dyes are used to stain tissues for microscopical examination. One dye shows the presence of fat in cells, another the presence of iron, another phosphorus, and so on. The chemical nature of the cells can thus be investigated under the microscope.

or *adipose* tissue. The fat forms a soft cushion to the body, fills up inequalities, and gives roundness and beauty to the figure. It acts, moreover, as a garment, protecting the body from loss of heat ; further, it is a most important storehouse of food to be drawn upon at times of need. Fat is deposited as tiny drops of oil within connective-tissue cells. The drops swell until they occupy almost the whole cell. The fat-cells are bound together by connective tissue into small lumps or lobules. This you can see on picking a lump of suet to pieces.

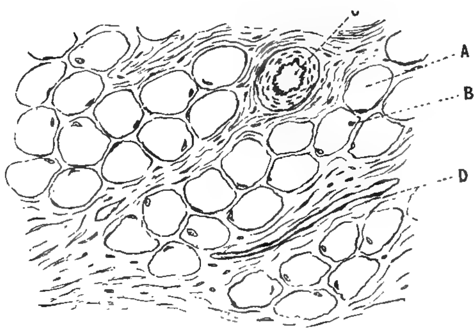


FIG. 55. Microscope, low power. Section through a morsel of fat. A, B. Fat-cells. C. Artery. D. Capillary. The fat-cells are held together by connective tissue and a network of capillaries.

At the temperature of the body the fat is not as solid as suet, but semi-fluid like the fat of a hot joint. Adipose tissue is supplied with many blood-vessels, which bring or take away fat according as the body is well or ill fed. In well-nourished animals fat is deposited not only under the skin, but also in the abdomen and on the external wall of the heart. Look at the inside of the carcase of either a sheep or bullock as it hangs in a butcher's shop. There are masses of suet at the back of the abdomen, as well as layers of fat coating the flesh on the outside of the body.

Ligaments. *Ligaments*, which unite bones together and

form the capsules of joints, are formed of white fibrous tissue. The bundles are packed tightly together, and the branching connective tissue-cells lie squeezed in between the bundles. Many ligaments contain elastic fibres; some are made up entirely of this kind of fibre. The great ligament in quadrupeds, by which the head is suspended from the spine, is formed entirely (as seen under the microscope) of large, branching, elastic fibres. In man, this ligament is of the same structure but insignificant in size, for the head of man rests on the top of the spine.

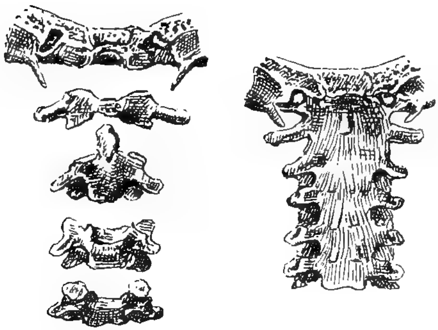


FIG. 56. Base of skull and upper four vertebrae shown separate and strapped together by ligaments.

On boiling white fibrous tissue in water a solution is obtained which, when cold, sets into jelly. By the action of the hot water a proteid substance (*collagen*) is changed into *gelatin.*

Bone consists of a basis of connective tissue impregnated with hard mineral salts. The tendons or cords of the muscles, which are inserted into and pull on the bones, are formed of white fibrous tissue arranged in the same way as in ligaments. A calf's foot consists mostly of bone, ligament, and tendon, and thus it yields, when boiled, calf's-foot jelly.

Cartilage or gristle. Hyaline cartilage. Buy from a butcher a sheep's trotter and a little bit of the breast of lamb. Open the joints in the former; study the ligaments which surround

the joints, and the smooth, glistening, articular surfaces lined with cartilage. Having broken asunder one joint, take a sharp razor and pare off the thinnest possible flakes or *sections* of cartilage. Place these on a glass slide, add a drop of salt solution, cover with a glass slip, and examine under the microscope.

Joint cartilage is formed of a transparent glassy substance in which are embedded oval or round cells in scattered groups of two or four.

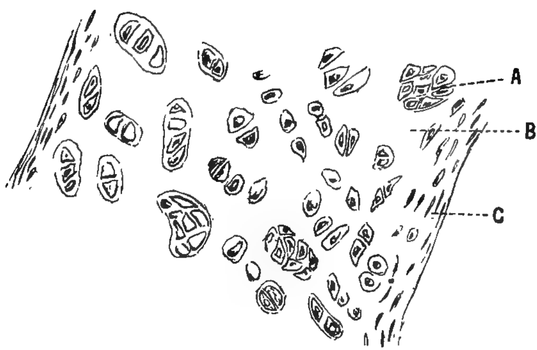


FIG. 57. Microscope, high power. Section through a piece of hyaline cartilage. A. Groups of cells embedded in B, a clear glassy substance. C. Cells flattened near the surface.

During the growth of cartilage the cells secrete the glassy, proteid substance, *chondrin*, which forms the matrix; and, at the same time, by dividing, form themselves into groups.

From the breast of lamb cut out and clean the cartilaginous ends of the ribs. You will find the pieces of cartilage are tough, flexible, and elastic. On cutting thin sections the glassy matrix and the cell groups will be again visible under the microscope.

This kind of cartilage is termed *hyaline*. Hyaline cartilage forms—

(1) A thin layer covering the articular surfaces in all movable joints.

(2) The cartilaginous parts of the ribs.

(3) The rings of the trachea and the walls of the larynx.

In the joints, hyaline cartilage acts as an elastic buffer. The intercostal cartilages give elasticity to the thoracic wall, thereby allowing a certain amount of movement. By rendering compression difficult the cartilage in the windpipe keeps it always open. Other varieties of cartilage are met with in the body.

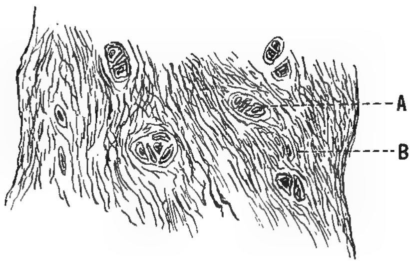


FIG. 58. Fibrous cartilage. A. Group of cartilage-cells. B. Fibres.

White fibrous cartilage. Between the bodies of the vertebrae there lie the intervertebral discs. These are composed of white fibrous cartilage. The fibres are pervaded with the proteid substance chondrin, and among them lie scattered groups of branched cartilage-cells. Here again the cartilage acts as an elastic buffer to the spine. The bony cups in which the heads of the femur and humerus fit, are deepened by rings of white fibrous cartilage; the same kind of cartilage lines those grooves in which tendons run, and forms the semi-lunar cartilages which exist in the knee-joint.

Yellow elastic cartilage. Yellow elastic cartilage is found in the gristle of the external ear, and in the epiglottis. It consists of a network of elastic fibres and cartilage-cells resting in a matrix of chondrin.

Buy an ox tail, split apart the vertebrae, and prepare

microscopical sections of the intervertebral discs. From the ear of an ox you can prepare sections of yellow elastic cartilage.

Bone. In the sheep's trotter you can examine into the nature of bone. All bones are covered with a fibrous membrane—the *periosteum*. This contains blood-vessels which run by minute passages into the substance of the bone. The periosteum can be stripped off the bone as a thin membrane. If this should happen from an injury during life the bare bone dies.

Saw one of the bones of a sheep's trotter in two, it will appear inside of a looser spongy texture. The *spongy bone* contains a reddish juice (*red marrow*). On the outside of the bone there is a thin layer of ivory-like *compact* bone.

In order that strength may be combined with lightness, a long bone such as the femur is hollow within.

Obtain a bone from the butcher and saw it along its length into half. The *medullary* canal, containing marrow which is here yellow with fat, becomes exposed thereby.

The canal extends right along the shaft of the bone, but does not enter into the articular enlargements at the end of the bone. These are full of spongy bone, like the small bones of the sheep's trotter. Somewhere near the centre a small tunnel pierces the shaft, and through this, blood-vessels pass to supply the marrow. The marrow is well supplied with blood; the vessels within the medullary canal communicate with those which, piercing the bone from the periosteum, supply the red marrow lying in the interstices of the spongy bone.

If you examine a section made with a saw through the head of a long bone, you will see that the bars of the spongy work are arranged in a definite manner, just as in an iron lattice-work bridge; some of the spicules of bone form *struts* to support pressure, while other spicules

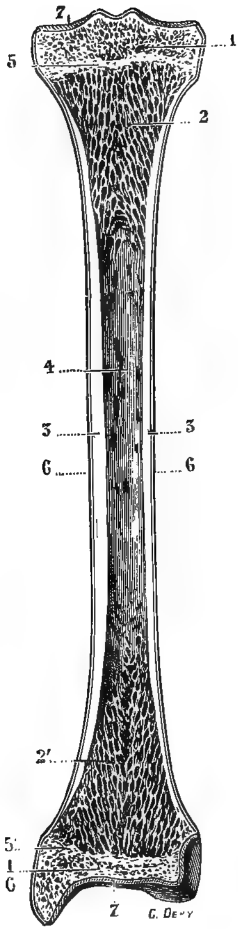


FIG. 59. Shin-bone (tibia) sawn in two along its length. 2. Struts and stays of spongy bone supporting 7, the upper and lower articular surfaces. 3. Compact bone forming the shaft. 4. Marrow cavity. 6. Periosteum.

unite the struts together and act as *stays*. From the study of the structure of the body not a few lessons may be learnt by the engineer.

In the flat bones also, such as the shoulder, hip-bones, ribs, and the flat bones of the cranium, there exists an outside coating of hard compact bone, and an inside light lattice-work of spongy bone forming struts and stays. A cylindrical long bone is not weakened by being hollow. Nothing is stronger than a hollow cylinder; thus pillars of bridges and the frame of a bicycle are made of hollow steel tubes.

Cut from old quill pens a number of hollow pieces, each an inch long, and stand these up on the table so as to support a board; you will find an enormous weight can be placed on the board without crushing the quills.

The composition of bone. Weigh a small fresh bone and then place it in a jam-pot full of dilute hydrochloric acid (2 parts of acid in 100 of water—the acid can be obtained from a druggist). Change the acid once or twice. After a week or two the bone will become soft and flexible, for the earthy mineral salts which pervade the bone and give to it the quality of hardness are dissolved out by the acid. Dry the

bone and weigh it again. If all the earthy salts are dissolved out, the bone should have lost 67 per cent. of its weight.

Weigh another small bone, place it in an iron spoon, and insert it into the middle of a red-hot fire. As the proteid matter chars, the bone becomes black, then as the combustion proceeds, it turns white, and finally a brittle crumbling bone is left consisting *entirely of earthy salts.*

Withdraw the spoon from the fire and weigh the bone. It should have lost 33 per cent. of its weight. Crumble up the bone in a jam-pot and add to it some strong hydrochloric acid, the earthy salts will then effervesce and dissolve.

The chemical composition of bone is as follows :—

Animal matter	33 per cent.
Phosphate of lime	57 " "
Carbonate of lime	7 " "
Other salts	3 " "
	100

In the last experiment carbonate of lime effervesces with the acid as carbon dioxide is formed, and escapes in a stream of bubbles:

$$CaCO_3 + 2HCl = CaCl_2 + CO_2 + H_2O$$

Calcium carbonate + hydrochloric acid = calcium chloride + carbon dioxide + water.

The proteid and earthy components of bone are so intimately combined that when one of the two is removed the bone retains its original shape.

From the bone softened in acid cut thin sections, and examine the microscopical structure of compact and spongy bone.

In the sections of compact bone you will see small canals (*the Haversian canals*), each surrounded by concentric layers or *lamellae* of bone. The concentric markings are produced by branching spider-like *bone-cells* which lie within the matrix of the bone. These cells, soft and

protoplasmic in structure, occupy spaces (*lacunae*) between the hard lamellae of bone.

The branches of the cells run through little channels in the bone (*canaliculi*). The canaliculi establish a communication between the lacunae on the one hand and the Haversian canals on the other. Within the Haversian canals there lie blood-vessels and marrow. From the blood-vessels nourishing juices (*lymph*) soak through the canaliculi and lacunae to all parts of the bone.

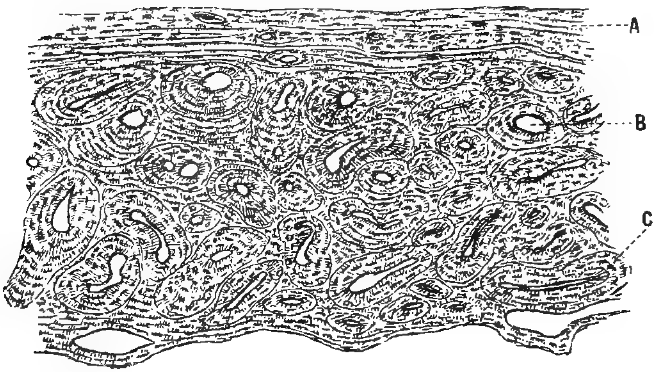


FIG. 60. Section through compact bone. A. Outside layers. B. Haversian canal. C. Lacunae, in each of which lies a branching bone-cell.

Spongy bone is formed of lamellae containing lacunae and canaliculi, but the lamellae form spicules of bone enclosing large irregular spaces filled with marrow, in place of the regular Haversian systems.

A softened bone can be torn into shreds with forceps so as to show its fibrous nature. The groundwork of bone is white fibrous tissue, yielding gelatin on boiling. This tissue is impregnated with earthy salts secreted by the cells which remain imprisoned in the lacunae after the growth of the bone is completed.

Certain ossified fibres run through the concentric lamellae

and fasten these together like pegs. Wherever a ligament or tendon joins a bone, the fibrous tissue pierces the bone and becomes part of its structure. Thus the union is immensely strong.

If a section of a hard dry bone be cut with a fine saw, and the section rubbed down on an oil-stone, it can be obtained thin enough to examine under the microscope. The Haversian canals are then seen as holes surrounded by lamellae of bone, while the lacunae and canaliculi, filled with dust and air, appear as black dots and lines, for the marrow and bone-cells have entirely disappeared.

The growth of bone. In both the developing chick or child the flat bones are first shaped in membrane, and the long bones in cartilage; later on both the membrane and cartilage are turned into bone. While a flat bone grows at its edges a long bone grows in length at either end. Between the articular ends and the shaft, there persists during all the period of growth (in man up to the twenty-fifth year) a piece of growing cartilage. As fast as the cartilage grows it is turned into bone. Certain of the bone-cells in the neighbourhood of this cartilage are very large (*giant-cells*). These eat up the cartilage, and into the spaces thus formed there grow white fibrous tissue, blood-vessels, and bone-cells; the last, by secreting earthy salts, form bone. The regular Haversian systems are moulded by giant-cells eating, and bone-cells building, in the same way as a sculptor moulds a face, scraping clay away here and adding it there. If a young pig be fed now and again on the vegetable dye madder, it is found that the bones are stained red at the seat of growth. Thus, if madder be mixed with his food for a fortnight the amount of growth during that period can be measured. The shaft of a long bone grows in width as the cells of the periosteum deposit concentric layers of bone on the outside; at the same time,

giant-cells within hollow out the medullary canal. If a silver wire be tied round a growing bone, it will first be covered up by the layers deposited by the periosteum, finally it may come to lie within the medullary canal. By means of the silver wire the growth in width may be measured.

Owing to the fact that the articular ends of young bones are connected with the shafts by pieces of growing cartilage, it happens not infrequently, as a result of accidents, that in young people these ends are torn off from the shafts.

CHAPTER XVI

THE MUSCLES.

'The skeleton of our body,' writes an old author, 'flesh doth cloath round; yet not with one entire lump, but parted as it were into ropes or puddings which the anatomists call muscles.'

Examine the leg of a dead and skinned rabbit. The flesh is separable into many distinct muscles. Each one is sheathed with a membrane of connective tissue and is bound to its neighbours by loose sheets of the same substance. At its either end a muscle is attached to bone by strong fibrous tissue, in the middle it swells into a belly of flesh.

Each muscle arising from one bone is *inserted* into another. In its course it passes over at least one joint, sometimes over more than one. A muscle when excited to contract shortens in length and swells in girth; thus it pulls upon the bones to which it is attached; if one of these be fixed, the other moves. The movement takes place in the joint over which the muscle passes. Think of a swing door; an elastic spring passes from the lintel across the hinge and is fixed to the door. When you let the door go, the spring contracts, and the door, moving on its hinge, shuts to.

So is the biceps muscle fastened at one end to the

shoulder-bone, at the other end to the radius. When it contracts you can feel the belly of the muscle swelling as it shortens, while the fore-arm, moving on the hinge joint at the elbow, closes up against the upper-arm. By catching hold of a post with your hand, you can fix the fore-arm; on then contracting the biceps, the shoulder is pulled down, for in this case it is the upper-arm that closes down upon the fore-arm. In nearly all cases the muscles can either move the bone from which they *have origin* or the bone into which they are *inserted*. A muscle is usually said to have *origin* from that bone which is the more fixed.

By separating the muscles at the back of the rabbit's thigh find a white cord, the *sciatic nerve*. Carefully following this nerve upwards, cutting through everything which hinders the view, but never losing sight of or injuring the nerve, trace it to where it issues by a series of roots from the spinal canal. Having done this, trace the nerve downwards and satisfy yourself that it gives off branches which run to end in the fleshy bellies of the muscles.

Each muscle is supplied by a nerve. The nerve, acting like a telegraph wire, sets the muscles in motion at the behest of the central office, the brain.

Think of a cabinet council in time of war. Telegrams arrive from all parts of the empire, the news thus brought is deliberated upon by the council, finally a course of action is decided upon, and telegrams are despatched ordering armies to move here, fleets there. So in the body, the organs of sense send despatches through the *sensory nerves* to the brain; the brain, deliberating upon the different despatches, commands, through the *motor nerves*, the muscles to move in such a manner as may best lead to the welfare of the body.

Cut across a rabbit's muscle. You will see it is composed of bundles which are bound together by loose films of connective

tissue. The bundles are in their turn composed of fibres which run lengthwise down the muscle. Take a minute fragment of muscle, lay it on a clean glass slide, and gently pull it apart with a pair of needles. Place upon it a drop of salt solution and cover with a slip of glass. On examining the preparation under the microscope you will see the fibres which compose the bundles.

Each fibre may be as much as an inch in length, but it is exceedingly slender in girth. The fibres consist of a peculiar kind of protoplasm marked by alternate dark and light bands. These cross the muscle at regular intervals. Hence the muscle is termed *striated*. Where a fibre has been crushed in preparation the muscle-plasm ruptures, and there may then come into view a tough, elastic, and transparent membrane, the *sarcolemma*, which encloses the striated muscle-plasm. Along the fibre, and lying beneath the sarcolemma, oval nuclei may be seen here and there. Fibres taken from the wing muscles of an insect—such as a bee, wasp, or beetle—when frayed out with needles, separate into exceedingly slender fibrils, and a granular material which lies between the fibrils. Each fibril is marked with dark and light bands, and may under fortunate circumstances be observed to contract while under microscopic observation; for the muscle of a cold-blooded animal does not die till some time after the death of the animal. When a fibril contracts the light bands seem to flow into and swell out the dark bands. The fibre of a rabbit's muscle can by special means be broken up into fibrils, but these are far smaller and are bound more tightly together than are the wing muscle-fibrils of insects.

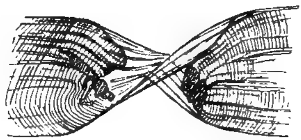


FIG. 61. Microscope, high power. Fragment of a muscle-fibre ruptured and showing the sarcolemma.

A muscle, then, is composed of *bundles*, the bundles of *fibres*, the fibres of *fibrils*, and the fibrils are marked by alternate bands of a darker and a lighter substance. The mystery of muscular movement lies hid in the dark and light substance of the fibrils. The muscles are richly supplied with blood-vessels, which run between and form a close meshwork round the fibres. In contact with every muscle-fibre there may be demonstrated by special

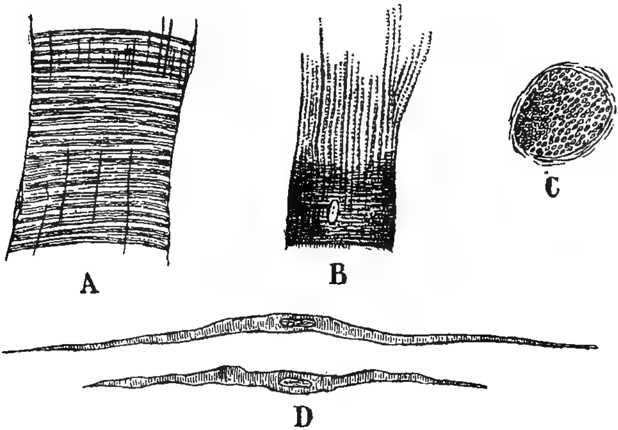


FIG. 62. A. Fragment of cross-striated muscle-fibre. B. Same teased into fibrils. C. Section of a muscle-fibre. D. Unstriped spindle-shaped muscle-cells from wall of intestine.

means the end of a nerve-fibre. The nerve-fibre at the point of contact swells out into a small protoplasmic mass termed *the end-plate.* At either end of the muscle the fleshy fibres change into white fibrous tissue, forming the tendons of origin and insertion.

Tendons. The tendons are fastened very securely to the bone, for the fibrous bundles run into and become part of the bone. It is easier to rupture a muscle or break a bone

than to detach a tendon from a bone. The tendons of some muscles are flat sheets; other tendons form long and slender white cords running to be inserted into bones at some distance from the belly of the muscles.

Pull off the tail of a dead mouse; you can obtain a bundle of long slender tendons looking like silken threads. Stretch these upon a glass slide, and, adding a drop of salt solution, examine them under the microscope. They are formed of many bundles of white fibrous tissue. A drop of weak acid (vinegar) will cause the bundles to swell and become transparent. Rows of little cells are then displayed which lie between the fibrous bundles.

The study of living muscle. When a man is killed by decapitation or hanging, death comes to him as a whole instantaneously, but many of his tissues do not immediately die. In the case of cold-blooded animals this fact is easily evidenced.

By one cut of the scissors you can decapitate (low down) the head of a frog and destroy such consciousness of life as that lowly animal possesses [1]. Having done so, pass a pin down the vertebral canal to destroy the spinal cord, then divide the skin all round the abdomen with the scissors, and taking firm hold of the skin below the cut, pull it from the lower limbs in the same way as a pair of trousers may be pulled from off a man. The muscles are thus exposed. They appear glistening and semi-transparent, soft and elastic to touch. At the back of the thigh, by carefully separating and pulling apart the muscles, you may expose a white cord, the sciatic nerve. Touch this with a needle, the muscles of the leg contract and the foot twitches. Prick the calf or thigh-muscles with the needle; each time you do this the muscles twitch. Both nerve and muscle are *irritable*, but only the muscle contracts. The nerve when irritated conveys impulse to the muscle and thus causes it to contract.

The contraction of the muscle lasts but a moment. It is followed by relaxation and a return to rest. Apply the wires of a galvanic battery (see Chap. V) to the nerve or muscle. On

[1] The frog can first be placed under a glass tumbler together with a piece of wool soaked in chloroform so as to destroy its sensibility.

making or breaking contact the muscle each time responds with a contraction. The contact of a hot needle produces the same effect. Muscle or nerve can not only be excited by tapping, electricity, and heat, but can also be stimulated by chemical substances of an irritant nature.

Expose the nerve of the other leg of the frog. Apply to this a few grains of salt; after a few moments the muscle will begin to violently twitch and finally pass into a condition of sustained contraction, *tetanus*, or spasm. Fatigue will shortly follow, for the muscle becomes exhausted; it then relaxes and ceases to be irritable. If the muscle be kept cool and moist, fatigue will disappear and the muscle again become irritable. The nerve, on the other hand, is killed where the salt touched it, and this part will no longer transmit impulses to the muscle.

Having determined these points, plunge the muscles into water at a temperature slightly greater than you can bear with the hand. The muscles contract, become stiff and inelastic, dull in colour and opaque. They will respond no more to stimulation, for they are now stiff and dead.

Muscle, like all protoplasm not protected by a horny skin or bark, is killed by a temperature of 45° C.

Rigor mortis. All dead animals stiffen when the muscles die; this stiffness is known as *rigor mortis.* It comes on much more rapidly when the muscles are fatigued, thus soldiers in battle and hunted animals stiffen almost as soon as they drop dead. The stiffness lasts for some hours, and disappears only when putrefaction commences. The flesh of animals should not be cooked when stiff, for the meat is then tough. A chicken should either be plucked and cooked immediately after it is killed, or else hung a day or two until rigor mortis has passed away. If fresh living muscle be minced, placed in a lemon-squeezer and squeezed, a thick juice (*muscle-plasma*) can be expressed. This juice rapidly clots and sets into a jelly.

There is within the muscle-plasm a proteid substance

termed *myosinogen*. This, when rigor mortis supervenes, clots and becomes *myosin*. The opaque appearance and stiffness of the muscle are due to the formation of myosin. Myosin can be dissolved in a 5% solution of common salt.

Chemical composition of muscle. Muscles contain 75 per cent. of water; combined with the water are the proteids myosinogen and albumin (the latter is like white of egg), a carbohydrate material called glycogen or animal starch, organic waste products, and mineral salts. Some of these substances are compounded to form the living contractile matter, others form the food material or waste products of the same. A resting muscle is *alkaline in reaction*. It will, like soda, turn blue a piece of blotting-paper moistened with the vegetable dye *litmus*. A muscle which has been made to contract until fatigued, or one that is dead, is like vinegar acid and turns litmus red. The acidity is due to the formation of sarcolactic acid, an acid similar to that produced in milk when soured by bacteria. Resting muscle is continually evolving carbon dioxide, but contracting muscle gives off this gas in increased amount. Energy is set free in the muscle by the breaking down of complex chemical compounds into simple substances such as carbon dioxide. Some of the energy is used up in doing work, some takes the form of heat and warms the body, while a little appears as electricity.

In electric fishes certain organs analogous to muscles are so altered in structure that almost the whole of the energy appears as electricity. The protoplasm in these animals is habituated to electrical currents, and is unharmed even by shocks of severe intensity. The electrical organs are used as organs of defence; they become fatigued, like muscles, with excessive work. The Indians of South America catch the electric eels by driving horses into the marshes; the horses, maddened by the shocks, stampede

and dash to and fro until the eels are exhausted and can be handled without fear.

If a small weight be tied on the tendon of a frog's calf (gastrocnemius) muscle, and the other end be fixed so that the muscle hangs suspended, the weight will be lifted when the muscle is excited to contract. In this way can the power of the muscle to do work be evidenced.

The tendon end of the muscle can be attached to a light lever so as to magnify the movement. A suitable lever can be made by passing a large needle through a long straw, near to one end of the straw, and then fixing either end of the needle on the top of a small lump of modelling wax or putty. The hole in the straw, through which the needle passes, must be made big

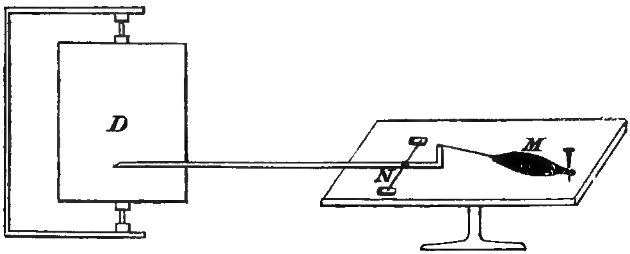


FIG. 62 *a*. *M*. Muscle attached by a pin to the lever stand, and by a thread to the lever. *N*. Needle forming fulcrum of straw lever. *D*. Drum.

enough for the straw to turn round the needle easily. The needle is the fulcrum of the lever. To the short arm of the lever a small piece of straw is fixed by sealing-wax in the vertical position. Attach the tendon of the muscle to this, and fix the other end of the muscle by a pin through the knee-joint. Such a lever can be made to write on a revolving drum covered with paper blackened in a sooty flame. The end of the lever will scratch off the black and *write a tracing* of the muscle's contraction—*a muscle curve*. A drum can be improvised out of a paint tin. A brass peg must be soldered to the centre of the top and bottom of the tin. A wooden frame can be put together to carry the drum and brass sockets fixed to it for the pegs to revolve in. The drum is covered with varnished paper, which is smoked in a fan-tail gas-burner or by burning camphor. The drum is set spinning, the lever brought to write on it, and the muscle excited to contract by an electrical shock from a battery.

By surrounding a *very delicate* thermometer with frogs' muscles, the formation of heat may be demonstrated by making these contract. The methods of proving the production of carbon dioxide in muscle will be described later on in the chapter on respiration.

The flow of an electrical current is not only found in an active muscle, but is the one sure sign we possess of anything happening within a nerve when an impulse passes down it. This change can be detected by a delicate galvanometer. But the study of electrical phenomena is too difficult to longer detain us here.

Spindle-shaped non-striated muscle-cells. Muscular tissue forms the outer coats of the stomach, intestines, ureter, and bladder, and enters into the structure of the walls of the air-tubes, arteries, and veins.

This muscular tissue differs widely from skeletal muscle. It consists of slender, spindle-shaped cells, each containing a spindle-like nucleus. The cells are not cross-striated, and are closely bound together into contractile bands and membranes. There are no nerve end-plates here, but the muscle-cells are supplied by a fine network of nerve-fibres.

Keep a piece of intestine (rabbit or frog) macerating for a day or two in some methylated spirit diluted with water (one part spirit to three parts water). Then cut open the intestine, scrape away the soft internal coat, and with needles fray out on a glass slide a tiny piece of the external muscular coat. Add a drop of water. Cover the preparation with a glass slip and look for spindle-cells with the high power of the microscope.

This kind of muscle contracts far more slowly than skeletal muscle. Another kind of muscle met with in the body is cardiac muscle. This consists of little short cells, composed of a dimly striated granular protoplasm. The cells are cylindrical in shape, and branch. Striated muscle is suited for short and rapid movements, while muscle composed of granular protoplasm executes slow and sustained movements. The contraction of the heart is both rapid and sustained.

CHAPTER XVII

THE MECHANISMS OF MOVEMENT.

THE amoeba by flowing out into protoplasmic processes streams in one or other direction. Infusoria lash the water with their cilia, and paddle to and fro. A jelly-fish contracts its umbrella, and, by expelling water from this hollow viscus, propels its body forward with rhythmic pulses.

A caterpillar, fixing alternately its head and tail, progresses in loops.

Worms fastening the anterior segments of the body to the ground, draw up the segments behind. These latter become broadened, and by contracting transversely in their turn propel the head end forwards, while the tail end is fixed.

In the higher animals the essential principle of locomotion is that the moving part first forms a bend or angle, and then is straightened out against some resisting substance. The principle is the same whether the locomotive members be fins, wings, or legs, and whether they move in water, in air, or on the ground; for air, water, and ground afford resistance to bodies which strive to displace them. The force exerted against a resisting substance reacts in proportion to the resistance, and imparts movement to the body of the animal.

A bird beats the air when it flies, a fish strikes the water with its fins. The wings of a bird are broad and powerful; these support a small and light body, while the resistance of the air to the stroke of the wings is but slight.

A gold-fish, by secreting gas within its swim-bladder, makes its body of the same density as the water, and thus hangs suspended without effort, in the same way as does a boy provided with a swimming-belt.

A man swims by slowly bending and rapidly straightening his limbs. He throws the water from him, and the water, resisting the repulsion, throws the man forwards with equal force.

In order to jump, a man bends his legs, and then, by suddenly straightening them, pushes the earth. Mother-earth is thrown in one direction, the man's body in another, and with equal force; but the force which will carry the weight of a man over a five-feet gate does not appreciably move the world.

The principle of the lever. When a burglar takes a crowbar, and placing it in the crack of a door uses it to force the door open, he avails himself of the principle of the lever. The crowbar is pressed against the lintel of the door, and this forms the *fulcrum*. The short arm of the bar moves in the crack; the long arm is wielded by the burglar.

In the body we find the bones, muscles, and joints arranged so as to act as levers.

There are three kinds or orders of levers:—

1. The fulcrum lies between the force applied and the resistance overcome.
   Example: a pair of scissors.
2. The resistance lies between the fulcrum and the force.
   Example: nut-crackers.
3. The force lies between the fulcrum and the resistance.
   Example: sugar-tongs.

Pass the crook of a walking-stick through the handle of a portmanteau or other convenient weight placed on the floor, rest the middle of the stick on the edge of a chair and, pressing the other end of the stick downwards, lever up the portmanteau. You have made a lever of the first order. On lengthening the arm of the lever on which the weight is slung, you will have to exert greater force, but the range of movement of the portmanteau will be increased. Shorten this arm and the opposite occurs.

Sling the portmanteau on the walking-stick, laying one end of the stick on a chair and holding the other end in your hand. You have now made a lever of the second order. When the weight is near the chair it requires little effort to support it. Allow the portmanteau to slip along the stick till it hangs near your hand,—it feels very heavy. Take a spring balance, place the hook round the end of the stick and, holding the handle of the balance, support the stick by it. Suspend the portmanteau in the centre of the stick between the chair and the balance, and read the position of the indicator on the dial. Now move the portmanteau along the stick till it hangs one foot nearer or further from the balance. Observe the indicator in each position.

Suppose the stick is four feet long, and the portmanteau weighs twenty pounds. When the portmanteau is suspended from the middle of the stick the chair will support half the weight, and the spring balance half (ten pounds). When the portmanteau is placed one foot from the balance and three feet from the chair, the balance will support fifteen pounds, and the chair five pounds. When the portmanteau hangs one foot from the chair and three feet from the balance, the chair will support fifteen, and the balance five pounds. It thus becomes clear that you can lift a weight by means of a lever which you could not raise with your own hands.

Next insert one end of the stick in the keyhole of a door, hang a weight on the other end and support the stick by means of the hand between the fulcrum (the keyhole) and the weight.

You have now a lever of the third order. If the hand be moved nearer the keyhole the weight becomes greater, but on raising the lever the weight moves through a much wider space than the hand.

By means of levers range of movement can be greatly increased. A lever can be employed either to increase power or to enlarge the range of movement. In the body of man the power is usually applied to the bones in such a way as to increase the rapidity and range of movement.

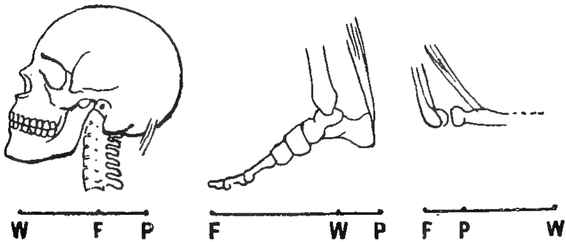


FIG. 63. Diagram of three kinds of lever action. F. Fulcrum. P. Power. W. Weight. I. The head is tilted back by neck-muscles. II. The toes rest on the ground, and the body is raised by the calf-muscles. III. The fore-arm is bent up by the biceps muscle.

In order that the muscles may be packed within the skin, so as to form the compact body of man, the power is applied at the insertion of the muscles close to the joints or fulcra.

Examples of levers in the body. First order: 1. Head jointed to the top of the spine, nodded backwards and forwards by the neck-muscles.

2. Fore-arm straightened on the upper-arm at the elbow-joint.

Straighten your arm and feel the triceps muscle contract at the back of the upper-arm. This muscle arises by means of a tendon from the scapula, and also from a rough line at the back of the humerus. It is inserted into the tip of the

ulna, where this bone forms the point of the elbow. The power is applied just above the elbow-joint or fulcrum, while the resistance, i. e. the weight of fore-arm and hand, lies beyond the fulcrum.

Range and rapidity of movement of the hand are here gained at the expense of power.

Second order: Stand on tiptoe, the calf-muscles contract, and the great tendon passing to the hind end of the heel-bone becomes taut. Power is applied at the back of the heel; the fulcrum is at the toes: the weight of the body falls on the feet at the ankle-joint. Power is here gained at the expense of range of movement.

Third order: 1. Bend the fore-arm on the upper-arm. You feel the biceps muscle contract. This muscle arises from the scapula by means of two tendons which pass over the shoulder-joint and unite to form the belly of the muscle. The biceps is inserted by a short tendon into the radius about an inch and a half below the elbow-joint. The power is applied there, the fulcrum is at the elbow-joint, the weight is that of the hand and arm. Rapidity and range of movement of the hand are here obtained at the expense of power.

2. Bend the leg at the knee-joint. You can feel the flexor muscles at the back of the thigh contract, while the tendinous cords (hamstrings) behind the knee-joint become taut. The fulcrum is the knee-joint, the power is applied just below this at the point of insertion of the hamstrings into the leg-bones, the weight is that of the leg and foot.

3. Straighten the leg at the knee-joint. Feel the contraction of the extensor muscles in the front of the thigh, and the movement of the patella knee-pan) upwards. The extensor tendon is attached to the patella, and then passes on to be inserted into the tibia, about two inches below the knee-joint. The power is applied at this insertion, the

fulcrum is above at the knee-joint; the weight, that of the leg and foot, lies below.

In both these last cases rapidity and range of movement are obtained at the expense of power.

Special movements. The centre of gravity. The upper part of a body in virtue of its weight always presses upon the lower part.

In every body there is some point which occupies the *average* position of the whole mass of matter of which the body is made up; this point is called the centre of gravity. Since the centre of gravity of a body always tends to take up the lowest possible position, it must lie over the base of support, for otherwise the body will topple over. In young children the centre of gravity is high, for the head is large and the little feet form but a narrow base. A slight push from behind brings the centre of gravity outside the base, and the child must quickly move forward its feet or tumble. The child has many tumbles, for the brain has to learn by experience how to rapidly carry out the appropriate movements by which the body may be supported when the centre of gravity is displaced. In adults, the centre of gravity is situated near the body of the last lumbar vertebra.

The erect posture. A dead man cannot without support be made to stand in the erect posture. If a man standing erect suddenly faint, the head tends to fall forwards on the chest; the trunk forwards at the hip-joints; the whole body forwards over the ankle-joints.

If a man lying on his back be picked up by his shoulders and feet, the head falls backwards, and the belly sags downwards.

The erect posture is maintained by the action of the brain and the muscles; if the brain suddenly cease to

send along the nerves messages to the muscles, the man falls in a heap. He has lost consciousness, and this may follow any violent shock, such as a blow on the head, or be due to some sudden disturbance in the circulation of the blood through the brain.

Although the body is balanced by the muscles in the erect posture, yet the weight of the body is borne by the bones and ligaments, and thus fatigue is kept from us.

In the stork, the bones of the leg can be so locked together, and the body balanced, that the bird restfully sleeps standing on one leg. In man, the maintenance of the erect posture is more of an effort, for the centre of gravity is easily disturbed, and the muscles must be frequently employed to maintain the balance. For this and other reasons man seeks his rest in the recumbent posture. The body is maintained erect by the following means :—

1. The head is balanced by the muscles so as to rest on the top of the vertebral column. The centre of gravity of the head lies in front of the joint; thus the head of a sleepy man nods forwards, the neck-muscles must act to keep it from doing so.

2. The vertebral column forms an elastic rod supporting the head and trunk, below it is fixed immovably to the broad pelvic basin; the weight of the abdominal organs presses down upon this basin. The centre of gravity of the body is situated near the front of the last lumbar vertebra.

3. If a plummet-line could be suspended from the centre of gravity, the line would pass a little behind the line which joins the two hip-joints. The trunk thus tends to fall backwards at the hip-joints. This is prevented by a strong ligament which passes from the pelvis to the femur across the front of each joint. By this ligament the joint is locked. The muscles passing from

the trunk to the thighs have simply to balance the body upon the heads of the thigh-bones. To do this but little effort is required.

4. At the knee the plummet-line dropped from the centre of gravity would pass through a line joining the posterior parts of both joints. The weight of the upper part of the body thus presses upon the flat articular surfaces of the tibiae. The great extensor muscles in front of the thigh prevent the knees from bending, and the body from falling backwards whenever the balance is disturbed. Owing to the check ligaments, which lock the femur and tibia together, the knee can neither be over extended nor bent to one side.

5. When a man is standing at attention a plummet-line drawn from the centre of gravity would pass slightly in front of a line joining the two ankle-joints, and the body is kept from falling forwards by the action of the calf-muscles.

6. The weight of the body is borne by the spring of the arch of the foot. The balls of the toes and the heel rest upon the ground.

The centre of gravity must always lie over the base of support. Thus a man stoops when carrying a child on his back, but walks erect if it be on his shoulders. He leans back and to the other side if the child be on his arm.

An old man widens his base of support by using a staff; the younger a child the more he tends to stand with his feet wide apart.

Walking. On standing on one foot the body is inclined to that side, so that a plummet-line dropped from the centre of gravity would fall within the base of support. The other leg is thus left free to move. In walking, one leg, say the right, is slightly bent at the knee and planted down in front of the other. The weight of the body is

thrown on to this leg, while the left leg, raised on to the toes by the action of the calf-muscles, forms a straight stiff rod. The left leg, by giving a push to the ground, next throws the body forwards. Thereupon the right leg straightens up, while the left, slightly bent at the knee, swings forward as a pendulum and comes down in front of the right. It is now the turn of the right leg to push off, and of the left leg to bear the weight of the body. The length and rapidity of the step in walking naturally depend on the length of leg. A duck waddles, while a hen runs. The longer a pendulum the slower it swings. Thus it is difficult for a long and a short man to keep pace, and a regiment cannot maintain a regular march when fatigued, for each soldier then falls into his own natural swing.

Running. In running, both legs momentarily leave the ground. The muscles act far more powerfully than in walking. The body is raised and thrust forward, not only by the contraction of the calf-muscles in the hind leg, but by the powerful action of the extensor muscles of the thigh, which straighten the bent knee of the forward leg. The body thus propelled forwards leaves the ground, while the hind leg swings forwards as a pendulum into the proper position for the next thrust. The exact changes which take place during rapid movement have been analysed by taking a succession of instantaneous photographs. These are taken on a long photographic film moved by clockwork placed in the camera. Such a film passed rapidly through a magic lantern by clockwork (cinematograph) faithfully reproduces the movement, for the different photographs succeed each other so rapidly that they fuse together to form in us the sensation of a moving object. In real life we only get a fused impression of the position of a moving animal. If an artist drew the horse in some

of the attitudes revealed by instantaneous photography they would appear ridiculous.

The muscular force of man. A stone held in the hand continually tends to fall, it is only while the upward pressure of the hand exactly counterbalances the downward pressure of the stone that the latter remains in equilibrium (balanced). The action of gravity is unflagged, unwearied, and so finally the man becomes fatigued and the stone drops.

It is far easier to carry a portmanteau with the arm hanging fully extended than to carry it with the arm bent. In the first case the bag is slung to the shoulder by the bones and tendons as it were by a rope, and the muscles have only to maintain the grip of the fingers round the handle.

The force of man can be measured by means of a spring balance. Hold a strong spring balance with either hand and pull on it with all your strength. Read the position of the index. Your pull will be equivalent to the pull of a certain weight, the number of pounds will be marked by the index. Repeat the pull several times in succession and at regular intervals of time. As fatigue comes on your force grows less and less. Measure your pulling-force when fresh in the morning and again when tired at night, when very hungry before a meal and again after the meal. Muscular power is increased by eating only a few lumps of sugar.

In most of the herculean feats of strength exhibited on the stage, the strong man supports enormous weights not by muscular effort, but by so placing his body that the bones form pillars of support on which the weight rests. To estimate the muscular work which a man does, measure the weight he lifts and multiply by the height of the lift.

On lifting a 2lb. weight 5 feet high, you will perform 10 foot-lbs. work.

When a man runs up stairs very fast, he may in lifting his body do seventy times more work in a minute than a labourer does in the same time who is steadily shovelling up earth. The man, however, is spent at the end of such an effort, while the labourer can continue to leisurely shovel for hours.

By following the longer and more circuitous path, work is made easier, for the force required is lessened in proportion to the length of the path. Thus a drayman finds it easier to pull a barrel of beer up an inclined plane than to lift it bodily up. The inclined board bears a large part of the weight of the barrel. Man is constantly devising similar methods to save the expenditure of muscular effort.

Inertia. Owing to *inertia* a heavy gate is difficult to move, difficult to stop; when a horse falls down, the vehicle runs on him; when a man on a bicycle runs full tilt into a low wall the machine suddenly stops, the man moves on and is thrown over the wall. Force is required to set matter moving, and force is required to again stop it. In all skilled movements the limbs are perfectly controlled by *antagonistic* muscles. For example, the hands in threading a needle are exactly balanced by the action of both flexor and extensor muscles. The muscles are always kept slightly contracted, in a state of tone; their tendons being taut they are ready to act on the bony levers without delay.

Friction. Force has not only to be applied to overcome and lift the weight of a body, but also to overcome *friction* and move one surface over another. Hook a spring

balance on to a pound weight, and drag the weight along the table, the balance will indicate the force required to overcome friction. Soap the table and try again, friction will be lessened. Friction is slight in the joints owing to their well-lubricated and smooth surfaces. Increasing the pressure between sliding surfaces acts as a brake. It is in this way that the foot is arrested when gliding along a slippery floor.

CHAPTER XVIII

THE BLOOD.

The clotting of blood. In whatsoever part the body be cut there wells forth blood. The fingers and face are richly supplied with networks of blood-vessels which bleed freely on injury. In other and less exposed parts of the skin the vessels are not so numerous, and here a surgeon may make large incisions and yet spill surprisingly little blood. Bathing or wiping a cut tends to make the flow of blood continue. To stop bleeding a piece of dry clean cotton wool may be placed on the wound. The blood then clots, and the clot drying forms a scab which closes the wound. The clotting of blood and the formation of a scab are Nature's method of dressing wounds, and man cannot follow too closely the natural plan. The fact that blood clots when shed is one of its most striking properties.

Tie a string tightly round the last joint of your first finger, bend the end of the finger so as to still further increase the congestion, and with a needle[1] prick the finger. This must be done sharply, just behind the nail. A prick here will give practically *no pain*, and a large drop of blood will exude. Before making the prick the needle should be held for a moment in a flame in order to ensure that it is clean and sterilised. Allow the drop to fall on to a clean white saucer, and to prevent drying cover the saucer with a piece of damp blotting-paper. After some minutes remove the blotting-paper and you will find that the drop has set into a jelly. The top part of the drop will be more fluid and transparent than the bottom layer, for the blood-cells sink, owing to their greater weight.

Find out when the butcher next kills. Take him two clean jam-pots which have been rinsed out with 0·8 % solution of common salt and ask him to collect some blood in each. In one pot place a small bundle of bristles or twigs drawn from a broom. With these he must be told to vigorously whip one of the samples of blood for a few minutes immediately after collection. The other sample the butcher must at once put

[1] A single point of a fine nib is better.

aside in a place where it will not be disturbed. Return in an hour or two and take away the two pots for observation. In the one that has been whipped the blood is quite fluid and bright scarlet in colour. Entangled in the bristles you will find some shreds of material. Wash these under a tap, there will appear a white fibrous substance—*fibrin*. In the other pot the blood has set into a jelly or clot, so firm that the pot can be turned upside down without spilling. From this clot there will gradually exude drops of a clear, straw-coloured fluid—*serum*. The serum increases in amount with time, and the clot shrinking finally floats in a bath of serum. Draw off some of the serum into a glass and keep it for further examination, then cut open the clot and observe its consistency and colour. On the outside the clot is scarlet, within dark blue-black. You can easily break up the clot with your fingers, it is of the consistency of a boiled custard or junket. Contrast the behaviour of a junket with that of a blood-clot. Junket is made by warming milk to body temperature (98·5° F.) and adding a few drops of rennet[1]. You will learn later what rennet is. The milk clots, but if you keep the junket till next day you find a shrunken curd floating in a bath of whey.

FIG. 64. Blood-clot, shrunken and floating in a bath of serum.

The microscopic study of clotting. Thus far you have determined that blood in the living body is fluid, that shed blood clots, that the clot shrinks and expresses serum, that whipped blood neither sets into a clot nor expresses serum, but yields a small amount of a white fibrous material (fibrin) entangled on the twigs with which it was whipped.

Now prick your finger and receive a drop of blood on a glass slide. Cover the drop with a slip of glass and examine it under the microscope (high power). You will see multitudes of round yellowish cells—the *red corpuscles*. These tend to run together into *rouleaux*, like little piles of coins. Here and there, in the clear spaces between the rouleaux, you may see one or two *white corpuscles*.

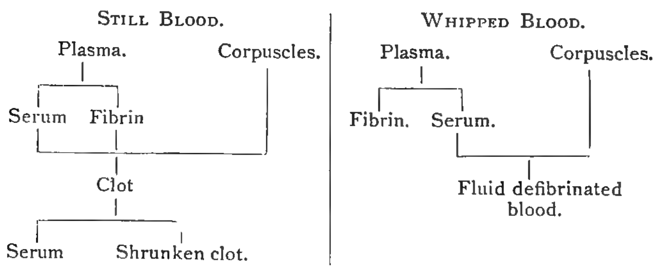
[1] Sold by grocers or druggists.

The corpuscles float in an almost colourless fluid, *the plasma.* If the preparation be left perfectly still for some fifteen minutes, you may be able to see under the microscope indications of minute fibrils pervading the fluid and holding together the corpuscles. The blood has now clotted and a network of fibrin entangles both the corpuscles and the fluid lying between the corpuscles into one jelly-like mass.

Spread out for microscopical examination a minute piece of clot on a glass slide, and you will see the fibrinous network and the corpuscles. Examine under the microscope a fragment of the washed fibrin obtained from the twigs with which the butcher whipped the blood. Here you see a meshwork of fibrils almost freed from corpuscles. Finally, examine a drop of serum under the microscope; it is a fluid almost colourless and free from either corpuscles or fibrin.

It is now evident that the clotting of blood is due to the formation of fibrin. When blood is whipped, the fibrin, as fast as it forms, is caught by the twigs. Only a certain amount of fibrin can be produced, and when this is removed the blood remains fluid and will not set into a clot. The fibrin formed in blood kept still pervades the whole clot, while the fibrin obtained on twigs by whipping shrinks into a few small shreds.

TABLE OF COAGULATION OF BLOOD.



Pull on some shreds of fibrin; they are elastic. A clot shrinks because the elastic network of fibrin slowly contracts, and by expressing the serum from its meshes, masses together the corpuscles.

Plasma, how obtained. Blood does not clot within the living healthy vessels. If in a horse, immediately after death, a large vein full of blood be tied up at either end, and the vein be cut out, the blood within remains fluid. It is enclosed in the healthy vessel and does not clot. The corpuscles owing to their weight sink to the bottom of the vein, and from the top a clear, limpid, but slightly yellow fluid, the plasma, can be drawn off. If the plasma be kept in a glass surrounded with ice it remains fluid, but if it be warmed it sets into a trembling jelly or clot. This clot shrinks into a few shreds of fibrin floating in serum. So soon as fibrin is formed the fluid is no longer called plasma but serum.

Salted plasma can be obtained by asking the butcher to collect blood into a pot half full of a strong solution of common salt. The salt in some way prevents the formation of fibrin, and the plasma collects at the top as the corpuscles slowly sink to the bottom. Directly the salted plasma is diluted with water and warmed it clots, for the action of the salt is then overcome. Plasma and serum set with heat into a white opaque mass, just as the white of an egg sets when boiled.

The proteids of plasma and serum. All these three fluids, plasma, serum and egg-white, yield proteids called *albumin* and *globulin*. Albumin is soluble in pure water, not so globulin. The latter is, however, soluble in water containing a weak solution of salts. Such salts are present in animal fluids. Albumin and globulin are both coagulated by heat, the coagulated proteid thus formed is a very insoluble substance. It can, however, be dissolved by the digestive juices of the stomach. Globulin can be precipitated by saturating serum with common salt. After filtering off the globulin precipitate the albumin can be thrown down by saturating the filtrate with ammonium sulphate.

The proteids in plasma and serum are also precipitated by strong nitric acid, and, like all proteids, are coloured yellow when heated with this acid. On adding ammonia the yellow colour is changed to orange. This is a general characteristic test for proteids.

Plasma differs from serum in containing fibrinogen in addition to serum albumin and serum globulin. This proteid can be separated from the globulin and albumin by half saturating serum with common salt.

The causation of clotting. *It is the fibrinogen that undergoes chemical change into fibrin when blood clots.* Coagulation of blood is hastened not only by warmth but by contact with foreign bodies. Blood will rapidly clot if shaken in a rough vessel, while it remains fluid for a long time if drawn into an oiled tube, or dropped into a bottle of oil. It is probably the death of the white blood corpuscles that causes the fibrinogen to clot. By their destruction certain proteid substances are set free, which act upon fibrinogen, but only in the presence of lime salts; there is thus produced a chemical change resulting in the precipitation of insoluble fibrin. If the minute quantity of lime which is present in plasma be removed, clotting will not take place. Lime can be removed and coagulation prevented by adding salts called potassium oxalate or sodium citrate to blood, for then a chemical change takes place and an insoluble salt of lime is precipitated. Taking sodium citrate as a drug makes the blood clot less readily, while taking a soluble lime salt increases the speed with which the blood clots. While blood does not clot within the living healthy vessels, it may do so in certain diseased states. In people who suffer from varicose or enlarged veins, a clot may sometimes form in the veins of the leg. The clotting is to be attributed partly to contact with the juices of damaged tissues, and partly to the death of corpuscles caused by the stagnation of the blood. Certain solutions of tissue-cells injected into the circulation of a living animal immediately cause the blood to clot within the vessels. Too small a dose may have just the opposite effect. Snake poison may act in this way, and death result from the stoppage of the circulation. The fluid

which collects under the skin in a blister or burn will, if added to the blood, hasten its clotting. We learn from these facts that each tissue in the body must keep to its own sphere, the tissue juices must not mix directly with the blood, nor the blood with the tissues. The living wall of the blood-vessels controls the give and take between the blood and the tissues. If this wall be broken, the blood clots at the injured point. By the clot the wound is sealed, the bleeding stopped, and the direct mixture of the blood with the tissue juices prevented. In very rare cases children are born in whom the blood possesses little or no power of clotting. In such it is almost impossible to stop bleeding, and thus they may die from a very slight wound owing to loss of blood.

Some general properties of the blood. 1. You cannot see through a layer of blood, since it is opaque. The multitudes of corpuscles stop the passage of light.

2. Blood colours blue the vegetable dye litmus, and, as far as this test goes, appears to be an alkaline fluid. It is however, really neutral.

3. Blood has a peculiar smell and saltish taste.

4. It is bright scarlet in colour when shaken up with air. Blood, if removed from contact with air, and kept still, owing to loss of oxygen, becomes dark reddish blue in colour. It is the blood corpuscles that use up the oxygen.

5. Blood consists of plasma and corpuscles.

6. The corpuscles are red and white, and the red are about five hundred times as numerous as the white.

7. The plasma forms about six-tenths, and the corpuscles four-tenths of the weight of blood.

8. Water forms ninety parts in every hundred parts of plasma. If one hundred grammes of plasma be dried, about ten grammes of dry proteid and salts are obtained. If the ten grammes be burnt, less than one gramme of mineral salts would be left as ash.

9. Water forms sixty-five parts by weight in every hundred parts of corpuscles. About thirty-five parts are proteids, and less than one part salts.

10. From both the corpuscles and plasma are salts of lime, sodium, potassium, and magnesium obtainable. The ash of plasma chiefly yields chloride of sodium or common salt, while chloride of potassium and phosphate of potassium form the chief part of the salts obtained from the ash of corpuscles.

11. The red corpuscles contain iron combined with proteid. By this combination the red substance *haemoglobin* is formed. Haemoglobin really combines with oxygen and forms scarlet oxyhaemoglobin. About 90 % of the proteid of the red corpuscles is haemoglobin.

12. Blood is estimated to form one-twentieth part of the weight of the body.

The red corpuscles. The red corpuscles of the blood

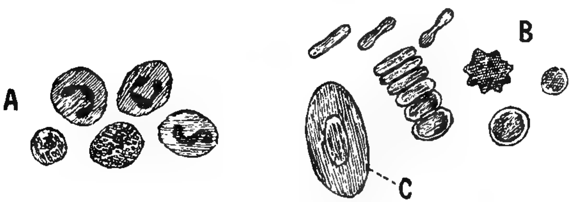


FIG. 65. Blood corpuscles. B. Biconcave, non-nucleated, disc-like, red corpuscles of man. C. Oval, biconvex, nucleated, red corpuscle of frog. A. White corpuscle, nucleated, some clear and some granular.

appear under the microscope as round, flat discs, thinner in the middle than at the edges, so they are said to be biconcave in form. There is no nucleus or definite structure to be seen within the red corpuscles.

Lurking within the interstices of spongy bone there lie the nucleated red marrow cells. From these cells are split off red lumps which pass into the blood stream and become moulded into red corpuscles. It is known that red corpuscles are constantly being destroyed in the body, and that the haemoglobin, or the red substance, within them

is changed into pigments which colour the excretions of the body, the bile, faeces, and urine. The red marrow cells as constantly produce new corpuscles, but it is not known exactly how long a corpuscle continues to circulate before it is worn out and destroyed.

A red corpuscle is not a living independent cell capable of division, but it is part of a cell filled with haemoglobin, and this being split off from the marrow cell is set to circulate in the blood stream for a special purpose. This purpose is the carrying of oxygen to all the tissues of the body.

Haemoglobin. Haemoglobin is a substance which greedily combines with oxygen. When exposed to air in the lungs it becomes bright scarlet oxyhaemoglobin. The tissues are still greedier for oxygen; thus when the red corpuscles come swirling through the tiny blood-vessels, the tissue-cells rob the haemoglobin of its oxygen, and the blood changes from scarlet oxyhaemoglobin to reddish-blue *reduced haemoglobin.*

The red corpuscles, being about $\frac{7}{1000}$ mm. or one three-thousandth part of an inch ($\frac{1}{3200}$) in diameter, are only visible under the microscope. It would take 140 corpuscles to span the thickness of a sixpence. They are very flexible and elastic, and so can become momentarily bent and distorted in passing through the tortuous and narrow vessels. There are roughly five million red corpuscles in one cubic millimetre of blood, that is, in a drop the size of a pin's head, and some 25,000,000,000,000 in the whole body.

How are they counted? Well, the finger is pricked and a drop of blood sucked up into a measure tube which holds 1 cubic millimetre. This quantity of blood is diluted 100 times with a salt solution and a drop of the mixture is placed in a little glass trough fixed to a slide. The trough is of a known depth and the bottom of it is ruled in squares of a known size. The number of corpuscles in each square is counted and the number in the c.mm. of blood calculated.

By special means, such as adding water to whipped blood, the haemoglobin can be made to pass out of the corpuscles into solution. The blood them becomes transparent, for the red colour is evenly distributed throughout the solution in place of being packed into numberless opaque cells. If the solution be allowed to evaporate, reddish crystals of haemoglobin separate out, and these can be obtained and kept indefinitely, like common salt, in a pure crystalline form.

After each corpuscle has shed its haemoglobin, there remains the colourless proteid shell or *stroma* in which the haemoglobin was stored. Haemoglobin is a proteid substance, remarkable for its wonderful colour, its greed for oxygen, its power of crystallising, and the fact that iron enters into its composition. The combination of iron in the molecule is, in some way, necessary for the proper execution of the function of haemoglobin—to wit, the carrying of oxygen to the tissues. Thus pale people, suffering from poverty of blood, take iron as a medicine.

The detection of blood. Think of a prism of glass, such as the glass pendants of candlesticks fashionable in drawing-rooms some years ago. When sunlight falls on such a prism, the light forms a band of colours or rainbow. In this you can distinguish red, yellow, green, blue, and violet. This band of colours is called the *spectrum*, and white sunlight is said to be compounded of these spectral colours. We shall have more to say on this subject later on, when treating of vision.

Now haemoglobin is red because it *absorbs* all the colours which go to make up white light, except red.

If you look at a spectrum through a glass vessel of water, containing just enough blood to redden it, you will only see red and no other colour. If the water be more faintly coloured with blood, some of the other colours of the spectrum may struggle

through, but absorption still persists, obliterating the greater part of the green.

If very dilute blood be examined with a prism placed in a special instrument, the spectroscope, two black bands of absorption are seen crossing the yellow and green colours, for by means of this instrument a very clear view of the spectrum is obtained. The two dark bands are due to oxyhaemoglobin, and these, on removal of the oxygen, are replaced by one broad band. The oxygen can be taken away from the haemoglobin by adding a few drops of a solution of ammonium sulphide, for this substance has a stronger affinity for oxygen and reduces the oxyhaemoglobin. On shaking with air the two bands come back again. A little potash or acid turns blood brown. Haemoglobin is split thus into *haematin*, the brown stuff, and *globin*, a proteid. Haematin is found in old blood stains. With potash and ammonium sulphide it gives dark bands, but the one in the yellow is less dark than the other. On shaking with air these bands disappear, and one faint band appears over the yellow in their place. Thus alkaline haematin can combine with oxygen and be reduced in turn. It is largely by the detection of these bands that the presence of blood in stains can be determined, and this test, combined with microscopic examination, is constantly made use of in cases of crime. Acid added to reduced alkaline haematin tears off the iron from haematin, forming an iron salt, and a coloured substance which can no longer combine with oxygen.

The study of osmosis in red corpuscles. If a drop of blood be mixed on a slide with a solution containing more salt than plasma contains, e. g. 2 %, the red corpuscles will shrink and wrinkle up, owing to the passage of water out of the corpuscles. If another drop be mixed with pure water the corpuscles swell and become globular in form, owing to the passage of water within. These facts should be carefully observed under the microscope, as they afford an excellent example of what is termed *osmosis* (see next chapter).

The white corpuscles. Interesting as is the function of the red corpuscles, that of the white cells of the blood is perhaps even more so. These are nucleated cells, not only

capable of division and multiplication, but endowed with the power of amoeboid movement, of flowing round and assimilating particles of food material. The white corpuscles of the blood are slightly larger than the red, and measure in diameter about $\frac{1}{2500}$ of an inch.

To see the white corpuscles at their best under the microscope warm a glass slide to blood heat, and thereon rapidly mount and examine a small drop of your own blood. In the spaces between the red corpuscles a white cell may here and there be seen flowing out into irregular shaped processes. Take a slide and rub it with fine emery paper. Then prick your finger and put a drop of blood on one end of the slide. Spread the drop into a film by gently drawing the edge of another slide, held at an angle of 45°, along the first slide. Let the film of blood dry. Stain it with a few drops of Leishman's stain (this can be got from Baird and Tatlock, Cross St., Hatton Garden, E.C.). Wash the stain off with distilled wash till the colour becomes pink. Dry the slide by pressing it between blotting-paper, and examine the film with the high power. Some of the white corpuscles appear filled with granules, and have an irregularly-shaped nucleus, others are clear with round nuclei, the nucleus in all is coloured blue by the stain. The granules are stained reddish-blue generally, but in a few cells they are stained bright red.

Function of the white corpuscles. The white corpuscles are the scavengers of the body. Owing to their remarkable power of independent movement they can creep out of the blood-vessels into the tissues. This they do whereever a tissue be inflamed or irritated. If the tissue-cells be destroyed, as in a wound, these corpuscles eat up the dead tissue, and by removing it, allow the living tissue-cells to grow and fill up the gap. If a man be tattooed the white corpuscles try and carry away the tattoo ink. Dust breathed into the lungs is by their means carried away, and thus a Londoner's lungs are constantly cleansed of coal-dust. By these cells the entry of bacteria is opposed, for they devour organisms wherever they attempt to effect

a lodgment. If the bacteria are the stronger the white corpuscles may die, and their dead bodies form matter or pus, while the tissue becomes inflamed. The white corpuscles are the wandering warrior-cells of the body for ever battling against the invasion of bacteria. The corpuscles, however, cannot eat the bacteria unless these have been acted on by plasma. The plasma prepares the feast.

Lymphatic glands and lymph. The supply of white cells is kept up by the marrow and lymph glands. The granular cells come probably from the marrow. The lymph glands are little round bodies about the size of hazel-nuts. They are to be found under the armpit, at the top of the leg in the fold of the groin, along the front of the neck, on each side of the neck, in the mesentery by which the intestines are suspended, at the roots of the lungs, and scattered here and there in other places. Taking their origin in the interstices of the connective tissue which pervades all the organs, fine lymphatic vessels arise and pass to the lymph glands. These vessels are provided with valves (like trap-doors) which allow the fluid to pass only in one direction. By the contraction of the muscles, by the movements of the body, and by the pressure due to contact of the body with surrounding objects, the fluid in the interstices of the tissues is continually expressed and made to flow along the lymphatic vessels. In doing so it filters through the lymphatic glands. The fluid which continually exudes from the blood-vessels into the tissues is called *lymph.*

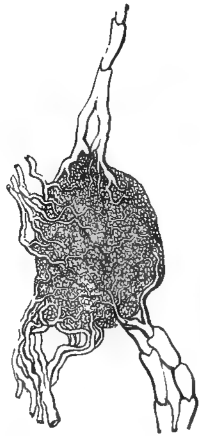


FIG. 66. Lymphatic gland, showing valved lymphatics entering and leaving it.

Lymph clots like plasma, and contains the same proteids and salts as are found in blood-plasma; but in lymph the proteids are less in proportion to the amount of water. There are very few red corpuscles, but many white corpuscles in lymph. A constant interchange of material goes on between the lymph which bathes the tissues and the blood in the capillaries. This interchange is controlled by the living cells which form the wall of the blood-capillaries. If these be injured by some irritant, such as the sting of a nettle or bee, a blistering fluid or burn, the lymph pours out too quickly and forms a blister. Certain kinds of food, such as crabs or mussels, will in some people act as a general irritant, and cause a nettle-rash all over the body. Most of the lymph that passes out of the blood-capillaries into the tissues finds its way back again into these vessels; only a small amount takes the longer pathway through the lymphatics into the veins. If the blood become too watery it can give up an increased amount of fluid to the tissues; if it become too thick, fluid passes from the tissues into the blood, and thus the amount of water in the blood is kept uniform. Any liquid injected, by means of a syringe, under the skin into the tissues is rapidly absorbed by the blood-vessels and carried away. In this way drugs can be administered.

The lymphatic glands consist of a connective tissue framework, the interstices of which are crowded with innumerable lymph-cells. Blood-vessels run in the framework and nourish the lymph-cells. The cells by undergoing division are constantly multiplying in number, and as the lymph percolates through the interstices of the gland many of these cells wander into the lymph stream; from thence they are carried on into the veins, for the lymphatics which leave the glands join together to form two larger vessels which finally open into the veins at the root of the neck[1].

[1] The vessel on the left side collects the lymph from the abdomen and legs, and is called the *thoracic duct* (see Fig. 119, p. 296).

It is to the lymph glands that the white corpuscles carry bacteria and particles of dust. The glands at the roots of the lung become in a Londoner black and gritty with the coal-dust stored within them. The glands in the armpit become coloured with tattoo ink in a man whose arm is tattooed. Whenever a part becomes inflamed from the entry and growth of bacteria, the lymph glands next to that part become enlarged and tender. Thus when you have

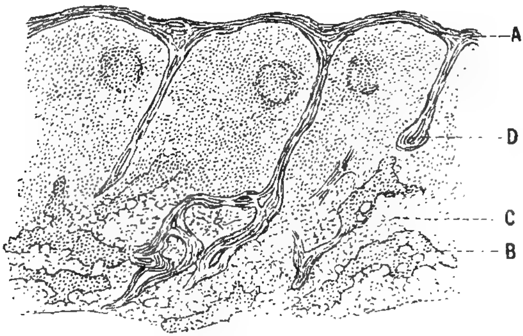


FIG. 67. Section through a fragment of a lymph gland. A. Fibrous coat sending partitions into C, the pulp of the gland. B. Denser masses of lymph-cells. D. Blood-vessel in fibrous partition.

a sore throat, glands in your neck may come down, that is, they swell and form perceptible lumps. The glands swell because the bacteria are carried thither by the white corpuscles, and the lymph-cells multiplying become active to destroy these organisms and prevent their entry into the blood stream. If perchance the bacteria gain the upper hand, the cells die; an abscess then forms in the gland, and the surgeon must then step in and aid nature by opening and cleaning out the abscess.

CHAPTER XIX

DIFFUSION. OSMOSIS. FILTRATION.

In the last chapter the interchange between the blood and tissue-lymph was discussed. It is necessary before proceeding further to study the ways in which substances can intermingle and pass through membranes.

Diffusion. This term expresses the power of molecules to slip past each other.

Place some crystals of salt at the bottom of a bottle of water; the salt will slowly diffuse into the water. Copper sulphate is the best salt to use as its blue colour makes its diffusion visible.

If equal weights of different substances be in turn placed at the bottom of a long column of still water, the substance will diffuse upwards, and the first trace of each will be found to reach the top in different periods of time. In one such experiment, common salt diffused to the top in $2\frac{1}{2}$ days, sugar in 7 days, and egg-white in 49 days. Proteids and all glue-like substances diffuse very slowly, for their molecules are very large and stick to each other.

Buy from the grocer a bottle of jelly, melt it by warmth, and let it set again in a dish. Mix some raw white of egg and common salt and place it on the jelly; the salt will slowly diffuse into the jelly, and this will become salt to the taste, but the egg-white will not diffuse, for its molecules are too large and tenacious to slip between the molecules of the jelly.

If a gas be set free in a room, it diffuses into the air, and the molecules of one kind of gas wander among those of the other. You know this to be so by the spreading of odours or perfumes through a room. A lighter gas spreads with greater velocity than a heavier gas, for the molecules of the former dart about with greater speed. Gases easily diffuse through a porous partition, such as an earthenware pot, for the molecules of gas are far smaller than the pores in the pot. Hence to retain gas within a balloon, the

coats of the balloon must be very carefully made, and be coated with layers of varnish to fill up all the pores.

Osmosis. Buy from the butcher two bladders or sausage-skins, free from cracks or holes. Fill one with a solution of salt, and hang it in a bath of water. Fill the other with water, and hang it in a bath of salt solution. After some time you will find the contents of the first bag have increased and the solution is less salt, while the contents of the second bag have shrunk and become salt. An exchange in either case takes place through the pores of the dead animal membrane, until the strength of the salt solution is the same on either side of the membrane, but the water passes through the pores more quickly than the salt. This kind of exchange is termed *osmosis*, and is of great interest to the physiologist; for between the blood and the tissues, the food in the alimentary canal and the blood, the ducts of the glands and the blood, there lies in each case a living animal membrane. Through these membranes exchange takes place, but since they are composed of living cells we have no right to expect them to behave exactly like a dead membrane, such as a bladder. To find out how a living membrane regulates the passage of substances through its pores is one of the most difficult subjects of physiology. The cells of the kidney allow one set of substances to slip through from the blood, and by rejecting all others form the urine. Similarly, the cells of the liver select the substances which form the bile, the salivary glands the saliva, and so it happens with each of the glands in the body. In each case the living cells permit certain substances to pass from the blood within them; these may either slip through unaltered, or after undergoing some chemical change within the cells. Thus the process of exchange may be divided into stages. For example, the living cells lining the alimentary canal first take up the digested proteid. This they act upon so as to chemically change its nature and then pass it on to the blood.

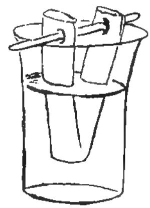


FIG. 68. Osmosis. Tube of parchment paper, containing a solution of egg-white and sugar, hung in a beaker of water. The sugar will pass through the membrane, while the egg-white will not.

Proteid and glue-like substances (*colloids*) cannot pass

through the pores of a dead bladder, and in studying the processes of digestion you will learn that such bodies are digested and dissolved by the action of the digestive juices so that they can pass through.

Substances dissolve in water in different ways. Salts, acids, and alkalies, generally dissolve with great changes of energy, e.g. dissolve potash or sulphuric acid in water—heat is produced. On the passage of an electric current through solutions of such substances they conduct the current by undergoing *electrolysis*, e. g. in the case of hydrochloric acid (HCl) the hydrogen goes to one pole and the chlorine to the other. The solution of such substances in water lowers the freezing-point and raises the boiling-point of water, because the particles of dissolved substance impede the coming together of the water particles to form ice or vapour. The molecules of such dissolved substance are so small that they can be pressed through an earthenware filter which has been soaked in gelatine. They diffuse easily through parchment or bladder. Next there are substances like urea and sugar, solutions of which will not conduct electricity, but otherwise behave as above. Lastly there are glue-like solutions such as those of proteids and starch. These will not conduct electricity, will not diffuse through parchment, will not pass a gelatine filter, and do not lower the freezing or boiling-point of water. Their particles are so large that by a special illumination the halos of light round them can be seen under the microscope, just as the halos round dust particles in the air can be seen in a sunbeam.

The subject of osmosis is very complicated, for the passage of different substances through the pores of any partition depends on many factors. For example, if a fluid on one side wets the wall of the partition and that on the other side does not, the former will more easily slip through. The passage depends, moreover, on the nature of the membrane. The molecules of the membrane may attract or repel the molecules of one or other of the substances in solution on either side of it. Thus it has been determined that frog's

skin allows water to pass more readily inwards, in order that the animal may not dry up. Eel's skin, on the other hand, allows water to pass more readily outwards, in order that the eel may not become soaked with water.

Strip off the skin of a dead frog's leg and tie it up as a bag. Weight the bag with a bit of lead and drop it into a glass of soda-water. Do the same with the lungs of the frog. The bag and lungs will become distended with carbon dioxide gas. If the lung of the frog is turned inside out it will not become distended with gas, for the honeycombed structure of the inside of the lung favours the giving off of gas bubbles. Soda-water contains carbon dioxide gas in solution, and the molecules of gas pass through.

As the external conditions of warmth, moisture, &c., constantly vary, the nature of a living membrane must be continually altering, and thus the same membrane may allow substance to slip through more or less easily at different times. A membrane that is damaged or dying becomes far more permeable; thus, after applying a blister, or after a nettle-sting or burn, the permeability of the wall of the blood-vessels is increased, and lymph transudes in increased amount.

Warmth increases molecular movement and favours osmosis; pressure on one side of the partition (as in the case of the blood-vessels) and the passage of an electric current tend also to push the molecules through a membrane.

Filtration. If the pores of a membrane be large, only coarse particles are retained from slipping through. Not only salts and egg-white in solution, but even blood corpuscles will pass through the pores of a piece of blotting-paper. Blotting-paper is used to *filter* off coarse solid particles from solutions.

To filter blood corpuscles from plasma, or fat droplets from milk, a membrane would have to be chosen with finer pores, such as an earthenware filter, and even then the end in view would be difficult to attain, for the pores become so quickly choked with corpuscles that filtration stops.

CHAPTER XX

THE CIRCULATION OF THE BLOOD.

The dissection of the heart. Ask the butcher to keep for you 'a sheep's heart with the heart-bag and pluck attached and the tubes cut long.' You will thus obtain the lungs and windpipe, the heart and large blood-vessels in an uninjured state.

The pericardium. The heart lies within the heart-purse or *pericardium*. This is a strong fibrous membrane forming a bag within which the heart lies. The inner surface of the pericardium is smooth and shiny, and so is the outer surface of the heart. These surfaces are moistened with a small quantity of pericardial fluid, so that the heart can beat within the heart-purse without friction. The pericardium is attached above to the point where the roots of the large blood-vessels leave the *base* of the heart; the pericardium does not end there, but turns back on its course and runs over the surface of the heart. Thus the pericardium has two parts, one closely covering the heart, the other forming the bag, and these are continuous above at the base of the heart. Place your hand in a sock, which has the foot turned inwards (as it comes home from the wash); your hand will be covered by a double coat like the heart is.

The bag of the pericardium is attached below to the central tendon of the diaphragm; above, strong bands of fibrous tissue pass down from the neck to be attached to the top of the pericardium and the base of the heart. The heart is thereby slung in position, and cannot twist over or tumble out of place

when a man shifts the posture of his body. This is not the only function of the pericardium, for it has allotted to it the important task of restraining the heart from becoming over-

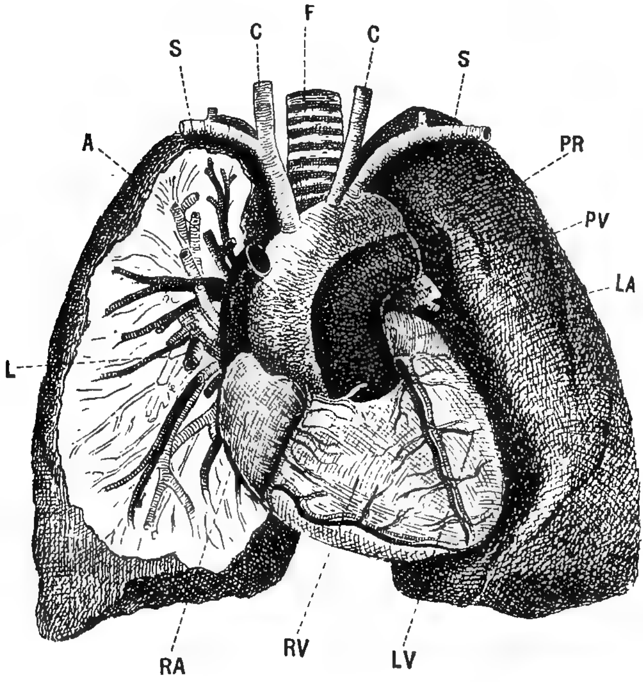


FIG. 69. Heart and lungs removed from the body. A. Aorta. C. Carotid arteries. F. Trachea. L. Lung cut open to show branches of pulmonary artery, vein, and air-tubes. LA. Left auricle. LV. Left ventricle. PR. Pulmonary artery. PV. Pulmonary vein. RA. Right auricle. RV. Right ventricle. S. Subclavian arteries.

dilated and surcharged with blood. In the same way the leather case of a football protects the bladder within it.

The chambers of the heart. Slit open the pericardium so as to expose the conical-shaped heart within. The *apex* of the cone is below and the *base* above. Running obliquely down the front of the heart from left to right is a groove filled with

fat. This groove separates the *left ventricle,* firm and thick, from the *right ventricle,* soft and flabby. The apex of the heart is formed by the left ventricle. Running up the middle of the posterior and flatter surface of the heart is a similar shallow groove.

The whole heart is divided by these grooves into a right side and a left side, and each of these is again divided by a groove, containing much fat, which circles round the top of the ventricles. Above this groove lie the *right* and *left auricles.* While the left ventricle is a thick and the right a thin-walled muscular chamber, both the auricles are thin-walled, and into these last open the large veins. Each auricle projects in front at the base of the heart as a flat crinkled bag of a bluish colour. These bags are the appendices of the auricles, and the latter take their name from the ear-like shape of the appendices. The greater part of the auricles lies at the back and sides of the base of the heart, and is concealed in front by the large arteries which issue from the top of the ventricles. The grooves seen on the outside of the heart not only mark out lines of division on the surface, but are the outward sign of partitions or *septa* which divide the heart into four chambers.

The right side is completely divided from the left side by a muscular partition running down the heart from top to bottom; thus there is no connection between the right and left cavities. Each auricle is divided from the corresponding ventricle by a transverse partition which, in each case, is pierced by a large hole, one leading from the right auricle into the right ventricle, the other from the left auricle into the left ventricle. Attached round the margins of each hole hang thin membranous flaps. When these are raised they meet together and so complete the partition. The flaps are the auriculo-ventricular valves set to guard the auriculo-ventricular orifices. It is necessary to cut open the heart in order to see these partitions and valves, but before doing so turn your attention to the vessels entering and leaving the base of the heart.

The vessels that enter and leave the heart. In front and from the top of the ventricles there issue two large white tubes which have thick walls, both extensile and elastic. These,

although empty, do not collapse. The one in front, rising from the right ventricle, is the *pulmonary artery*; the other, issuing from the left ventricle behind the pulmonary artery and soon curving over to form an arch, is the *aorta*, the great artery which supplies with blood all the body except the lungs. The butcher will probably have cut through the aorta about six inches from the heart. Springing from the top of the arch of the aorta are three large arteries which pass upwards to supply the head, neck, and arms. These also will have been cut short by the butcher. Just beneath the arch of the aorta the pulmonary artery divides into right and left branches which enter the respective lungs. There are generally large masses of fat round the roots of the big vessels. Carefully remove the fat in order to trace the two short *pulmonary* veins which leave the lungs and enter the left auricle. In man there are four pulmonary veins. The right auricle is entered by two large veins, the *superior vena cava* bringing the blood from above, the *inferior vena cava* from below. These two veins will have been cut short by the butcher. The veins have thin, inextensile walls which, unlike those of the arteries, fall together. Passing a penholder down the superior vena cava, feel for it within the right auricle; then, pushing the probe further

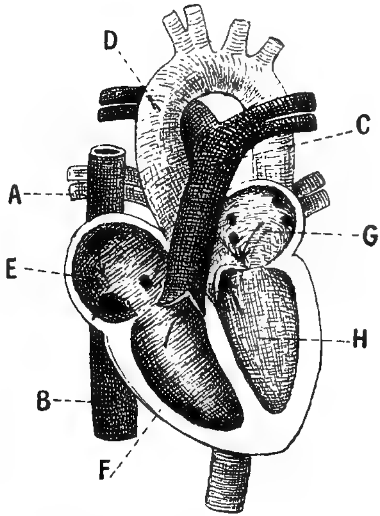


FIG. 70. Diagram of the cavities of the heart and blood-vessels. A. Vena cava superior. B. Vena cava inferior. C. Pulmonary artery. D. Aorta. E. Right auricle. F. Right ventricle. G. Left auricle, with four pulmonary veins opening into it. H. Left ventricle. The arrows show the direction of the circulation.

down, pass it through the right auriculo-ventricular orifice into the right ventricle, wherein you can feel it with your fingers. Up the inferior vena cava you can pass the penholder through the right auricle until it issues from the superior vena cava.

The pulmonary semi-lunar valves. Now cut through the pulmonary artery just above its origin from the ventricle, and look within. You will see three little membranous flaps each forming a little pocket. These are the semi-lunar valves of the pulmonary artery. Pour some water into the pockets; the valves will close together and prevent the water entering the ventricle. Pass a penholder between the valves down into the heart. You can feel it lying within the right ventricle. Next cut open the right auricle from the superior to the inferior vena cava, and observe the glistening, smooth surface of this irregular-shaped cavity. The wall of the auricular appendix is covered with little irregular bands or bars of muscle.

The tricuspid valve. Opening the right auricle widely, look down into the right ventricle, and see the three irregular-shaped valve-flaps hanging down round the margin of the right auriculo-ventricular orifice. To these flaps are attached little white tendinous strings (*chordae tendineae*) which arise from muscular projections of the wall of the ventricle (*papillary muscles*). Insert an ordinary tin funnel through the semi-lunar valves of the pulmonary artery, and through this run water from a tap into the right ventricle. On doing so the flaps of the right auriculo-ventricular or *tricuspid* valve will immediately float up and close the auriculo-ventricular orifice in a wonderfully perfect way. The strings (chordae tendineae) prevent the valve from being turned inside out, just as an umbrella is kept from such mishap by cross wires.

The aortic semi-lunar valves. Now cut through the root of the aorta just above the top of the left ventricle; on looking within, you will see three semi-lunar valves similar to those found at the root of the pulmonary artery. Pour a stream of water upon these; they will close and prevent the entry of water into the left ventricle.

The mitral or bicuspid valve. Open the left auricle widely so that you can see the left auriculo-ventricular orifice and the

two valve-flaps hanging down within the left ventricle. These also are attached by chordae tendineae to papillary muscles and form the *bicuspid* or *mitral* valve. Pass the funnel through the aortic semi-lunar valves into the left ventricle and pour water within; the mitral valve will float up and close the left auriculo-ventricular orifice.

The ventricles. Finally slit up the anterior wall of each ventricle by cutting upwards from the apex to the base, and on either side of the groove seen on the front surface of the heart.

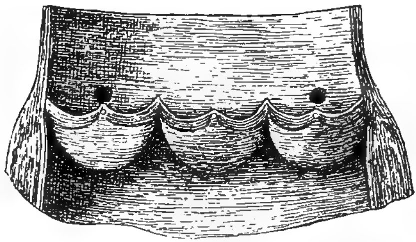


FIG. 71. Root of the aorta cut open to show the three semi-lunar valves. The two black dots are the openings of the coronary arteries which supply the heart with blood.

Carefully notice (1) the thickness of the muscular wall of the left ventricle in comparison with that of the right. (2) The papillary muscles standing up as blunt, fleshy cones from the inner walls of the ventricle. (3) The white strings (chordae tendineae) passing from the apices of these to the irregular-shaped membranous valve-flaps. (4) The bands and bridles of muscle which beset the lower part of the internal surface of each ventricle. In the right ventricle one or more bands may cross the cavity and act as stays to prevent over-distension of this chamber. (5) The glistening, smooth lining of the cavities of the heart. (6) The muscular partition which separates the right from the left ventricle and the right from the left auricle. (7) The openings of the pulmonary artery and the aorta into the right and left ventricle respectively.

The action of the heart as a pump. Buying another sheep's heart you must next carry out the following important and instructive experiment. Take two pieces of glass tube, each about a foot long and half an inch in diameter (these can be obtained from a chemical store). Inserting one into the right auricle,

through the superior vena cava, tie it firmly within with a piece of string. With another piece of string tie up the opening of the inferior vena cava. Having done this, tie the other tube into the root of the pulmonary artery in such a position that the end of this tube lies just above the semi-lunar valves. Now, holding the heart up by the two glass tubes, fill with water the tube placed within the right auricle, and then rhythmically squeeze the right ventricle with the hand. With each squeeze the water will sink in the vena cava tube and rise in the pulmonary artery tube. This proves that the heart is so

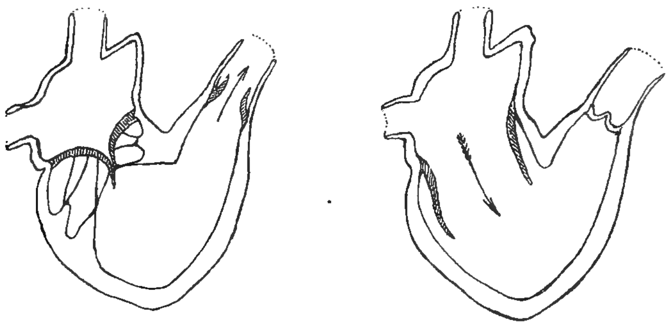


FIG. 72. Diagram of right side of heart. Systole—Auriculo-ventricular valves shut. Chordae tendineae drawn taut. Semi-lunar valves in pulmonary artery open. Diastole—Auriculo-ventricular valves open. Blood entering from auricle into ventricle. Semi-lunar valves of pulmonary artery shut.

constructed with valves that fluid can be pumped only in one direction, namely, from the auricles to the ventricles and from the ventricles to the arteries. The water runs as follows: (1) From the vena cava tube into the right ventricle. (2) On squeezing this cavity, the tricuspid valve shuts to and prevents the return of fluid to the auricle. (3) At the same time the semi-lunar valves are forced open and the fluid is driven into the pulmonary artery. (4) On ceasing to squeeze, the water runs again into the right ventricle from the tube in the vena cava, while it cannot return from the pulmonary artery for the semi-lunar valves have shut to.

This is the way the living heart acts :—the blood flows

into the right auricle from the venae cavae, and from thence into the right ventricle; the muscular wall of the latter then contracts, and, having expelled the blood within into the pulmonary artery, again dilates and refills. Simultaneously with the above operations, blood flows from the pulmonary veins into the left auricle, and thence into the left ventricle; the latter, in its turn, contracts and expels the blood within into the aorta. The two ventricles fill together and empty together with perfect rhythm, and day and night the heart, without ceasing, maintains by its beat the wonderful circulation of the blood.

Discovery of the circulation of the blood. How do we know that the blood circulates? Civilised man spent thousands of years in study and observation before he advanced to the discovery of this simple fact. It was reserved for the genius of an Englishman, Harvey, by means of a few simple experiments to demonstrate that the blood moves in a circle; thereby he laid the foundation of the modern science of physiology.

Examining the body of a freshly killed animal you will find the veins in the root of the neck and in the belly filled with blue blood.

About the surface of your own body, running beneath the skin, you can see the blue veins. On tracing the veins and squeezing the blood within them towards the heart it becomes clear that they can be emptied into the right auricle and thence into the right ventricle. From the right ventricle there passes the pulmonary artery to the lung, but this, in the dead animal, is empty of all except air. On cutting open the lungs you cannot with the naked eye trace any connection of the pulmonary arteries with the pulmonary veins. These latter may, however, contain blood. On opening the aorta it will appear empty, and on dissecting out the branches of the

aorta it is impossible with the naked eye to trace any connection between these and the veins of the body.

So great were the difficulties which beset the path of the early anatomists that they were led to believe that the veins sucked the nutriment from the intestines and thence carried the blood to the organs of the body. The lungs they imagined fanned the heart to cool it, while in the left heart they thought a wonderful vital spirit was formed of the greatest tenuity, which spread through all the arteries to vivify the body.

'Whatsoever part is wanting of nourishment,' writes an old anatomist, 'it calls on its small veins; those the greater veins; these the liver; the liver the mesarick veins; these the maw (stomach); but the maw shrivels itself if it hath nothing to give, and this is that which we call hunger, when we stand in need of moist nourishment and the chops are dry. The heart, the fountain of life, doth boil up out of the finest parcel of blood, a little flame called a vital spirit, and it panteth by reason of its heat incessantly,' &c.

Experiments by which Harvey demonstrated the circulation. First of all he learnt to notice the valves in the veins of the limbs.

Stroke your arm downwards towards the hand; little knots or swellings will at once rise up in the course of the veins.

On dissection of such veins there would appear at each knot small membranous flaps or valves placed within so as to allow the blood to flow in one direction only, towards the heart. From the presence of these valves it became obvious to Harvey that the blood cannot flow in the veins from the heart to the limbs, but must flow from the limbs to the heart.

Leaving the higher animals with their complicated lungs,

Harvey turned his attention to simpler forms, such as snakes, frogs, and fishes. If a string be tied tightly round the neck of a common grass-snake to prevent loss of blood, and the animal be decapitated, these observations can be carried out without entailing any suffering, for the circulation continues for some time in a dead cold-blooded animal: (1) If, after exposing the heart, the vena cava be tied up, the heart and aorta are seen to become empty of blood, while the veins become turgid. (2) If, on the other hand, the aorta be tied up, both the heart and veins become turgid, while the aorta empties. (3) If the aorta be opened, blood spurts out in jets from the end nearest the heart at the same time as the ventricle contracts. (4) If the inferior vena cava be opened, the blood will well out slowly and continuously from the end furthest from the heart. On compressing the body of the snake upwards towards the heart the blood will flow more rapidly from the cut vein.

On binding a ligature tightly round your own arm, after first squeezing the blood upwards from the veins, you will find the part below remains pale and bloodless and soon begins to feel numb. This is because the arteries are compressed and no blood can enter the part. Loosen the ligature, and the part will immediately flush with blood. If you bind the ligature but lightly, the part below will become swollen and blue, for the arteries which lie more deeply and have tenser walls are left open, while the veins are compressed; thus, the blood continues to enter by the arteries, but cannot escape by the veins.

If the pulmonary artery be opened in an ox immediately after it has been felled by a butcher with a pole-axe, it is found to be distended with blue blood, like that in the veins, and this blood spurts out with each contraction of the right ventricle. On opening the pulmonary veins bright scarlet blood wells forth from the lungs. It is clear then that the blood comes by the veins to the right side of the heart, and from thence passes by the pulmonary

artery through the lungs, where it changes its colour from blue to scarlet. Returning to the left side of the heart by the pulmonary veins, the scarlet blood passes by the aorta through the tissues of the body, thence it passes to the veins, having again become blue in the course of its wanderings. Harvey was certain of these facts, but he was unable to determine exactly how the blood passed through the tissues, or what were the hidden connections between the arteries and veins.

Microscopical study of the circulation. By the invention of the microscope, and the consequent discovery of the *capillaries* by Malpighi, the final and crowning proof of Harvey's doctrine was obtained, but not till some years after the death of that great master.

On examining under the microscope any transparent living membrane, such as the web of a frog's foot, or a tadpole's tail, the blood can be *seen* circulating from the smallest arteries through the tiniest transparent tubes or capillaries. The arteries branch into the capillaries, and these again join together to form veins. Throughout the tissues there exists the finest network of blood-vessels, by means of which every cell in the body is supplied with nourishment.

To see the circulation, obtain a tadpole (in the early summer); gently wrapping a piece of wet blotting-paper round its body and leaving the transparent tail exposed, lay it on a glass slide. The animal will under these conditions remain quiet, while you, without the infliction of any pain, can observe under the microscope the ceaseless flow of blood through the capillaries in its tail.

In the small arteries the stream is so rapid that you will not be able to detect the shape of the blood corpuscles; in the smallest capillaries, on the other hand, so narrow and tortuous is the passage, that the red corpuscles must march through in single file. Now and again a corpuscle,

becoming twisted or bent, hangs for a moment suspended at some angle, and generally where one capillary branches off from another. The red corpuscles move in the central axis of the stream where the current is swiftest; to the outside there moves a layer of transparent plasma, and in this the white corpuscles may be seen here and there to roll along, sticking now and again to the wall. There is *friction* in the blood-vessels. The outermost layer of plasma wets the walls and is quite stationary, the next layer rubs against this and moves but slowly, and the next against this, and so on, until we come to the centre or axis of the tube where the red corpuscles are scurrying along fastest of all. Similarly in a stream there is friction between the successive layers of water gliding along, and the water in the centre of the stream flows the fastest. This friction is of the greatest importance, for it opposes the flow of the blood through the small arteries and capillaries. If the friction increase, the flow may stop, and if the friction be lessened the flow becomes faster.

The thicker and less watery or more *viscous* the blood, the slower will be the flow; thick treacle, you know, will not flow as fast as water. The wider the tube and the smoother its wall, the less will be the friction and the easier the flow. If the tail of the tadpole be injured, as by the application of a grain of mustard, the corpuscles will stick together in the capillaries and the flow will cease; the mustard damages the capillary wall and alters the nature of the blood. This change takes place whenever a tissue becomes injured and inflamed, and as the circulation ceases the damaged tissues die. All around the damaged area the blood-vessels dilate and bring more blood to the part. Thus an inflamed part is redder and warmer. In repair of the injury the dead tissue is first removed by the scavenger action of the white corpuscles which creep out from the neighbouring blood-vessels. Ultimately, then, by the new growth of tissue-cells, the damage is repaired.

Course of the circulation. The *general course of the circulation* can be studied in a dead rabbit. Starting from the left ventricle in man the blood passes into the arch of the aorta. From the top of the arch there arises on the right side the innominate artery, on the left side the left carotid and left subclavian arteries. The innominate soon divides into the right carotid and right subclavian arteries. The two carotids pass up the neck and supply the head and brain; from thence the blood is brought back by the jugular veins which enter the superior vena cava. If a man, attempting to commit suicide, severs the carotid artery while cutting his throat, he rapidly dies; fortunately this artery is not easily cut by the would-be suicide. If the neck be forcibly compressed by the hands of a garotter, the flow of blood in both carotids is suddenly stopped, and the victim

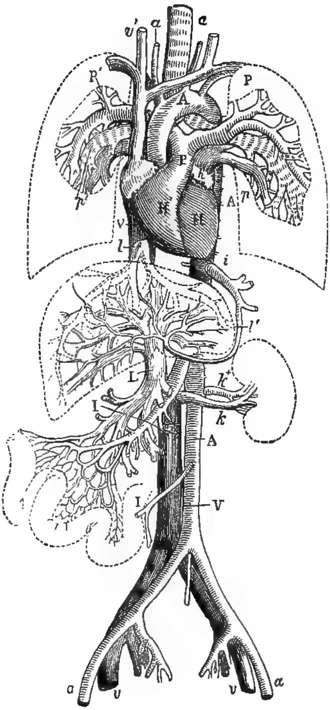


FIG. 73. Diagram of the circulation. H'. Right ventricle. P'. Pulmonary artery. P. Lung; the branches of the pulmonary artery and vein, *p'*, and the air-tubes, *p*, are seen entering the lungs. *h*. Left auricle. H. Left ventricle. A. Aorta. *a*. Carotid arteries to head; next to these arise the subclavian arteries which supply the upper limbs. I. Intestine. *k*. Kidney. The aorta is shown giving off branches to these organs. Finally, the aorta divides into branches which supply the pelvic organs and the lower limbs. V. Vena cava inferior. Receiving blood from lower limbs, pelvic organs, kidneys, and liver, it enters the right auricle. The portal vein, L, is shown carrying the blood from the intestines to the liver. *l*. Hepatic vein. *l'*. Hepatic artery *v'*. Superior vena cava bringing blood from head and upper limbs to right auricle.

faints from want of blood in his brain. The right and left subclavian arteries supply respectively the right and left shoulder and arm; from thence the blood is returned by veins which open into the superior vena cava. The main artery of the arm can be felt pulsating as it runs along the inner edge of the biceps muscle.

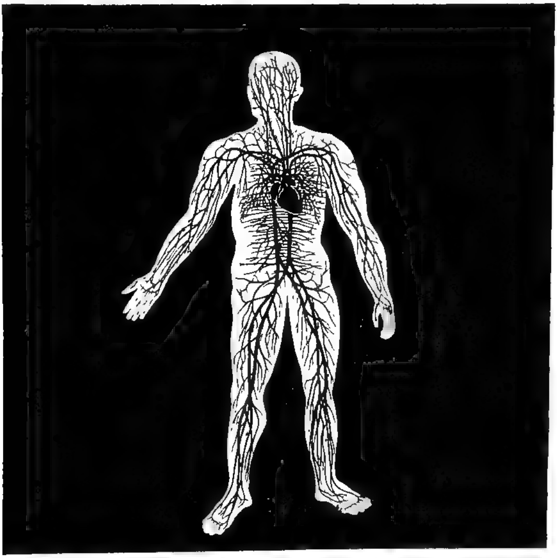


FIG. 74. General diagram of the distribution of the blood-vessels.

If a cord be tightly twisted round the upper arm, bleeding from a severed artery in the limb below can be at once stopped. If, on the other hand, a vein be severed in the limb, the ligature must be applied below and not above the wound.

Having given off the above-mentioned large branches, the aorta bends over and, lying against the vertebral column, runs down the back of the thorax. Here it

gives off a succession of small branches. These arteries follow the course of the ribs and supply the wall of the thorax with blood. They are hidden under the ribs, and so are not easily injured.

Reaching the abdomen, the aorta gives off large branches to the stomach and others to the intestines, called the mesenteric arteries. A branch goes to the liver (the hepatic artery), and another to the spleen. A little lower down a large branch passes on either side to each kidney (renal arteries). Finally the aorta, now dwindled in size, divides into two main branches; from these arise branches to the pelvic viscera and the two femoral arteries. The latter pass down the front of the thigh on the inner side. At the upper part you can feel the femoral artery pulsating. The femoral artery, having given off branches to the thigh, winds round to the back of the knee, and thence sends branches to supply the leg and foot.

To stop bleeding from an artery severed in the leg, a cord must be twisted tightly round the thigh.

From the lower limbs the blood is returned by veins which join together and form the vena cava inferior. This passes up in front of the spine, and receives the blood from the veins of the kidneys. The mesenteric veins, however, do not open directly into the vena cava, but join together to form the portal vein, which passes to the liver and ends in a network of capillaries within that organ. From these capillaries there arises the hepatic vein, which opens into the vena cava inferior at the point where the latter pierces the diaphragm.

Owing to this arrangement the food material, which is absorbed from the intestines and enters the mesenteric capillaries, is first conveyed by the portal vein to the liver. Thus the food does not reach the general circulation until after it has been dealt with by the liver.

Finally both the superior and inferior vena cava open

into the right side of the heart, and from thence the blood passes into the pulmonary artery, and traversing the capillaries of the lungs reaches once more the left ventricle. The network of blood-vessels throughout the body is developed so minutely, and to such an extent, that if you could dissolve away all else and leave the vascular system standing, the figure of a man and all his organs would still be represented.

By injecting with a syringe warm liquid gelatin (coloured red) into the aorta of a dead animal, the whole vascular system can be filled. The gelatin sets solid when it becomes cold, and by cutting up the organs into thin slices and examining these under the microscope, the network of blood-vessels can be most clearly observed. By adding a preservative to the gelatine, such as formol, the body can be embalmed.

CHAPTER XXI

THE CIRCULATION OF THE BLOOD (*continued*).

Structure of the arteries, capillaries, and veins. The aorta and pulmonary artery, as can be seen in the sheep, are extensile and elastic tubes, in this respect resembling india-rubber tubing. The venae cavae, on the other hand, while being much less extensile and elastic, are more capacious and have thinner walls than the great arteries. The great arteries are largely made up of yellow elastic tissue, the veins of white fibrous tissue. In the walls of both are many spindle-shaped but not striated muscle-cells. The veins, although thinner than the arteries, are not less strong; it requires very great fluid pressure, far above that exerted by the heart, to burst open either a vein or an artery.

The whole vascular system, heart, arteries, capillaries, veins, is lined within by a layer of flat pavement cells; each cell is exceedingly thin, and by a wavy outline is cemented to its fellows. This layer affords a smooth, glistening surface along which the blood can flow with ease. Outside it there exists in the large arteries a thick middle coat formed of yellow elastic membranes, intermingled with which are some white fibrous tissue and spindle-shaped muscle-cells. This coat endows the arteries with extensibility and elasticity. An outside coat

of strong fibrous tissue not only protects the arteries from injury, but prevents their over-distension.

The walls of the smaller arteries are distinguished from the large by a great increase in the number of muscle-cells, and decrease in that of yellow elastic membranes. Quite a thick coat of muscle-cells encircles these vessels. The large arteries are above all extensile and elastic,

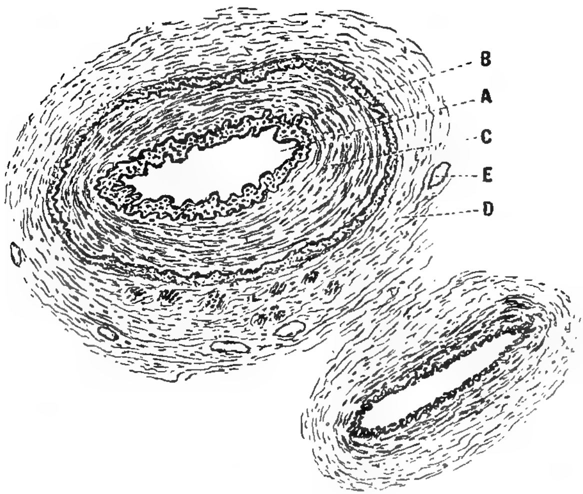


FIG. 75. Section through a small artery and vein. A. Artery lined with flat, scale-like cells. B. Elastic membrane. C. Muscular coat. D. Connective-tissue coat. The vein is much thinner and has less muscle and elastic tissue. E. Capillary supplying outer coat with blood.

the small arteries are essentially muscular, contractile tubes. As the smaller arteries branch into capillaries, the muscle-cells become less and less numerous until in the capillaries there is nothing left but the layer of flattened cells separating the blood within from the tissues without. The arteries bring the blood to the tissues, but it is through the thin capillary wall that exchange takes place, by which each tissue-cell obtains nourishment from and

gives up its waste products to the blood. As the capillaries join together to form the small veins, muscle-cells again appear and coat the walls of the latter. The large veins are more capacious than the corresponding arteries, and their walls are composed of much less yellow elastic and more white fibrous tissue, sparsely intermingled with which are some spindle-shaped muscle-cells. The capillary networks are so connected that if one branch of an artery be

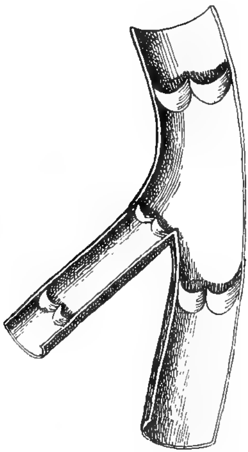


FIG. 76. Vein cut open to show the valves.

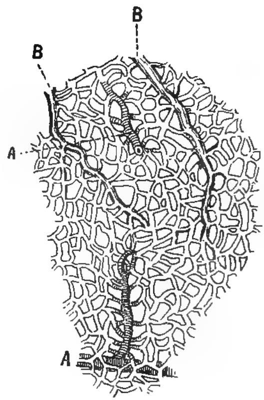


FIG. 77. Microscope, low power. Diagram of a capillary network. A. Artery. B. Veins.

tied, the blood finds its way by the other channels. Thus to destroy the life of any organ all the arteries to that organ must be tied. The veins are connected together by cross branches, as you can see in your arm, and thus if one vein be stopped up, the blood finds its way along the others.

On the inside of a sheet of skin taken from the abdomen of a dead frog, you can see the network of vessels most beautifully displayed. To see the minute structure of the small

arteries, veins, and capillaries, obtain a sheep's head (sawn in half) from the butcher, and pull off some of the membrane (pia mater) which closely invests the soft substance of the brain. With needles pull to shreds some of this membrane on a glass slide, add a drop of vinegar, and examine under the microscope. You will see many little arteries and veins with capillaries branching off from them; these lie among the white fibrous tissue of which the pia mater is composed.

Structure of cardiac muscle. We must now turn back again to the heart and study the minute structure and the nature of the contraction of *cardiac* muscle.

Take a minute fragment of the muscular wall of the sheep's heart, place it on a glass slide, and fray it out as finely as possible with needles. Add a drop of salt solution, and covering with a slip of glass, examine the preparation under the microscope (high power).

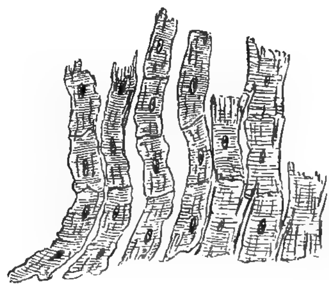


FIG. 78. A fragment of heart muscle teased to show the minute branching, striated muscle-cells.

The muscle is composed of minute branching cells, each containing an oval nucleus and formed of protoplasm exhibiting dimly cross striations. The cells join together by their branches and are thus linked in bands which run over the heart. Many of the bands start from the auriculo-ventricular groove and run downwards to the apex, where they turn inwards and run up the inner surface of the heart and back to the auriculo-ventricular groove. These bands, when they contract, shorten the ventricles. Other bands circle round both ventricles, and, by contracting, compress the ventricles so as to diminish their girth. Similar bands of muscle-fibres encircle the auricles.

Cardiac muscle-cells differ from skeletal muscle-fibres in that the former branch and are very much shorter and less striated than the latter. Each cardiac muscle-cell also has but one nucleus, and is not bounded by a membrane or sarcolemma.

From the root of the aorta, just above the semi-lunar valves, there arise two *coronary arteries*, which running at first in the grooves of the heart finally dip into the muscle and subdivide into a multitude of capillaries. Between every two or three muscle-cells there lies a branch of the capillary network set to nourish them with blood. From these capillaries there arise *coronary veins* which convey the blood back to the right auricle.

The smooth, shiny, internal lining of the heart (endocardium) is formed of a layer of flat cells, joined together like tiles in a pavement, edge to edge in one continuous sheet. Between these and the muscles there lies a little connective tissue, and this tissue also runs between the bands of muscle-cells and helps to bind them together. The external or pericardial surface of the heart is also lined with flat pavement cells resting on a thin bed of connective tissue.

The contraction of the heart. The beat of the heart can be observed in the decapitated frog or grass-snake, for the heart continues to live some time after the death of these animals.

The heart can be exposed in the decapitated frog by cutting away the front wall of the chest and opening the pericardium. The cavities can be seen to contract in a definite order and with perfect rhythm, first the openings of the big veins (forming the sinus venosus in the frog), then the auricles, and lastly the ventricles. The heart can be cut out bodily and laid on a glass plate; it will continue to contract as regularly as before.

It is clear from the experiment that the rhythmic beat

of the heart does not depend on the nerves, but is the mysterious inborn faculty of heart muscle. In this the heart differs from skeletal muscle. The heart again will only beat rhythmically; it cannot by any form of stimulation be thrown, as skeletal muscle can, into a continuous state of spasm. The heart of a sheep or ox cut out and observed immediately after death would also be seen to beat for a minute or two, but it soon dies owing to the want of warm nourishing blood. If the ventricles be cut open during the minute allowed for observation, the papillary muscles can be seen contracting at the same time as the wall of the ventricles, so as to pull taut the valve-strings or chordae tendineae. The heart of a mammal, cut out of the body, can be made to beat well and for hours by circulating through it an appropriate solution of salts saturated with oxygen gas. Even a dead man's heart has been made to beat again by this means.

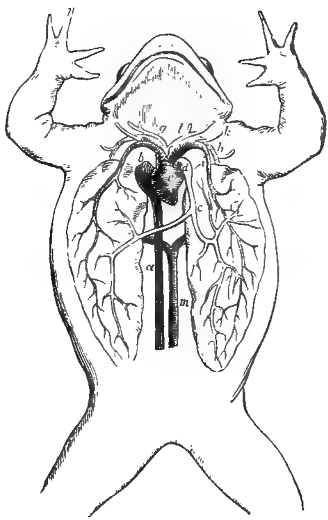


FIG. 79. Diagram showing the heart, lungs, and large blood-vessels of a frog.

The cardiac cycle. The contraction begins then in the big veins (vena cava and pulmonary), and presses the blood on into the right auricle and left auricle respectively. From the latter it flows into the ventricles. Next the auricles give a short sharp contraction and empty their contents into the ventricles. The blood pouring into the latter eddies round under the auriculo-ventricular valves,

and floats these up so that their thin membranous flaps are brought in contact so soon as the inflow ceases. There follows immediately the contraction of the two ventricles. The muscular wall of each contracts and compresses the blood within, the auriculo-ventricular valves in each are closed, so that the blood cannot return to the auricles, and thus, as the pressure rises above that in the pulmonary artery and aorta respectively, the blood is expelled; these elastic vessels are in their turn expanded by the expulsive force of the heart so as to receive the blood. As the ventricles contract and expel the blood, the papillary muscles, by shortening to a corresponding extent, keep the valve-strings taut. This prevents the auriculo-ventricular valves from turning inside out.

The ventricles do not expel the whole of the blood within them, for the upper part of their cavities cannot be obliterated by the contraction of the muscular wall. So soon as the muscle ceases to contract the ventricles expand and the semi-lunar valves shut. The expansion of the ventricles is brought about chiefly by the elastic rebound both of the papillary muscles and the columns of muscle in the lower part of the ventricular cavities. These have been compressed together during contraction.

Press together two pieces of india-rubber; on suddenly ceasing to press you will find they rebound from each other.

As the blood is expelled from the ventricles, the outflow at first is rapid, for the pressure of the blood within the ventricles is greater respectively than that within the pulmonary artery and aorta. The outflow becomes slower as the big arteries become distended with blood; it finally ceases when the pressure within these arteries becomes equal to that within the ventricles.

As the outflow diminishes the semi-lunar pockets are filled by eddies of blood, and the valve-flaps are brought nearer and nearer, until finally they shut to. The closure is effected without any jar, at the very moment when the

outflow ceases and the ventricles begin to expand. The heart, as a good pump should, works with the least possible jar; during the contraction of the ventricles blood has been steadily pouring from the veins into the auricles. The moment the ventricles expand the auriculo-ventricular valves open, and blood begins once more to fill their cavities. For a brief moment the ventricles remain dilated and at rest, then again the auricles contract, and the *cycle* of changes is once more repeated. The period of contraction is termed the *systole*, the period of rest or pause the *diastole*.

The frequency of the heart-beat. You can count the number of times the heart beats per minute by feeling the pulse at the wrist. Here (on the thumb side) can be felt the throb of the heart transmitted along the radial artery. In young infants the pulse beats almost as fast as you can count, i. e. about 130 times a minute. From infancy up to fourteen or fifteen years of age, the frequency of the pulse becomes steadily lessened, and finally settles down to a constant rate of about 60 to 70 beats per minute. This, the average for all adults, may vary in certain individuals. Tall men, as a rule, have a less frequent pulse; but Napoleon, a short man, is said to have had a pulse rate of 40 per minute. In nervous people the heart is easily excited by the emotions to beat quickly, and sometimes to such an extent as to produce a feeling of palpitation. Perhaps the cool and calm deliberation with which Napoleon carried out his great achievements was connected in no small degree with his steady and equable heart.

Warmth always stirs up protoplasm to greater activity, and thus hot drinks reaching the stomach, which lies next to the heart, may make the latter beat faster. By fever the pulse is always quickened. On hot days and in hot Turkish baths the pulse is quicker, for the blood must be sent more rapidly to the skin so that the body may be cooled. Exercise accelerates the heart very greatly.

Count your pulse while resting on a sofa; say it is 60; stand up, the rate may become 70; run very fast upstairs, the rate may then reach 120 per minute.

Duration of systole and diastole. If the heart beat 75 per minute, each cardiac cycle (systole and diastole) must occupy $\frac{60}{75}=\frac{8}{10}$ secs. Of this time the systole of the auricles occupies about $\frac{1}{10}$ sec., the systole of the ventricles about $\frac{3}{10}$ sec., the diastole of the auricles $\frac{7}{10}$ sec., and of the ventricles $\frac{5}{10}$ sec. If after running upstairs the pulse rate be doubled, it is the period of diastole which is shortened, and thus the heart obtains far less rest. Similarly, in high fever the resting time of the heart is lessened, while the high temperature causes the protoplasm of the heart muscle to discharge energy and waste quickly. During each systole of the left ventricle the muscle-fibres of the heart must, by their contraction, raise the pressure of the blood within the cavity above that in the aorta, for otherwise the semi-lunar valves could neither be opened nor the blood expelled. Now the coronary arteries which supply the heart arise from the aorta, and the branches of these arteries lie between the muscle-fibres. During systole these fibres squeeze out, not only the blood lying within the ventricle, but that in the coronary vessels. So soon as diastole occurs the blood rushes into the coronary arteries once more. It follows from this that the muscle-fibres can only obtain nourishment during diastole, and if diastole be shortened, the heart has to do more work for less pay (nourishment). These facts make clear the danger of the heart failing during high fever or over-strain.

The cardiac impulse. *The beat or impulse of the heart* can be felt by laying the flat of the hand over the region of the left nipple. At each contraction, the ventricles become hard and tense; at each diastole, soft and flaccid.

Now and again, as a result of accidental injury or malformation from birth, the heart may be exposed. Harvey studied the heart-beat of a man from whom the sternum had been shot away by a gun. On touching the exposed heart no pain was felt, and the man remained quite unconscious of the contact. The skin, as you know, is highly sensitive, for it forms the outer covering of the body, and nerve-endings are set therein to tell the brain what is happening in the outside world; the heart and other viscera are in this respect quite otherwise, for when healthy they are not sensitive to contact. Thus a man's bowels may protrude, as a result of an accident, and yet if they be hidden by his clothes, he may be entirely unconscious of the fact. If a finger be laid upon the exposed heart, it is at each systole pushed away by the sudden hardening of the muscle. Similarly the chest-wall is pushed out by the systole at the point where the heart comes in contact with it. The point of impulse varies according to the position of the body.

Lying on your left side, you can feel the impulse just below the left nipple; turning on the right side, the impulse almost vanishes, for the heart now strikes the chest beneath the sternum. Lying on your back, the impulse will be felt between the fifth and sixth ribs, an inch below and a little to the right of the left nipple.

The sounds of the heart. *Two sounds* are produced during each beat of the heart.

Place your ear against a friend's chest over the region of the left nipple; you will hear sounds which are best represented by the syllables 'lūb dŭp.' Buy a penny cherry-wood pipe, cut the stem in half, and join the two ends together again by fifteen inches of rubber tubing. Place the bowl of the pipe over your own heart and the mouthpiece of the stem in one ear. You have thus made a *stethoscope*. With this listen to the sounds of your own heart. The *first sound*, 'lūb,' is heard most

clearly over the seat of the impulse; the *second sound*, 'dŭp,' over the level of the second rib cartilages, beneath which lie the aorta and pulmonary artery.

The first sound is still to be heard if the heart of a sheep or ox be cut out immediately after the death of the animal, that is to say, so long as the heart muscle continues to forcibly contract. The sudden tension of the muscle produces a sound just as does the sudden tension of a piece of string. This sound occurs at each systole of the ventricles. The auriculo-ventricular valves and chordae tendineae are also made taut at each systole, and they too vibrate and help to swell the first sound. If these valves be diseased and do not shut properly, but leave a hole, then during systole some of the blood rushes back into the auricle; this produces a blowing sound or murmur. Thus, by listening to the heart, we can tell whether the valves are defective. The second sound of the heart occurs at the end of the systole of the ventricles, and is caused by the tension of the semi-lunar valves. As the ventricles cease to contract eddies of blood shut the valves. As the ventricles dilate, the blood within the aorta and pulmonary artery, by pressing upon the shut valves throws them into tension. A sound is produced thereby, just as by the vibration of any tense membrane, such as a drum.

By tying a bladder over the end of a long and wide-bored glass tube filled with water and held vertically, a sound can be produced each time the bladder is pushed up with the finger and allowed to drop down again, for it then becomes tense under the pressure of the column of fluid within. This experiment can be done by tying the glass tube into the root of the aorta or pulmonary artery and the sound is then produced by the semilunar valves.

Blood pressure. In such an apparatus you can feel the pressure of the fluid exerted upon the bladder at the bottom of the tube. This pressure is due to the weight of the water, and the higher the column the greater is the pressure.

Obtain from the druggist a bulb syringe; on to the nozzle of this fasten ten feet of rubber tubing. Let the open end of the syringe, which contains a valve (=auriculo-ventricular valve) dip in a basin of water, and place the far end of the rubber tube so as to hang over the edge of the basin. Rhythmically compress the india-rubber bag of the syringe (=ventricle). The water will be thereby raised, and forced in jets out of the rubber tube. It circulates from the basin to the basin.

Next, by twisting a wire (hairpin) round the rubber tube, close up the open end, almost but not entirely. On working the syringe under these conditions the fluid will issue, not only in jets with each squeeze or systole, but also continuously between the squeezes, i. e. during diastole. By closing up the orifice the fluid cannot be so rapidly driven out, and the force of the hand is mostly spent in distending the rubber tube. Since the fluid cannot pass back to the bag of the syringe owing to a valve (=semi-lunar valve), the elastic recoil of the rubber tube continues during diastole to force the water onwards through the orifice. In other words, during systole the force is stored up in the stretched elastic tube, and this force during diastole is spent in maintaining the flow.

It is clear, then, that if an intermittently acting pump be fitted to a rubber tube ending in a narrow orifice, an intermittent outflow from the pump can be converted into a continuous outflow from the orifice. On this principle, fire-engines, garden watering-engines, &c., are made, and on the same principle nature has contrived the circulation of man. The heart is the intermittent pump, the arteries are elastic tubes, the little arteries form narrow tubes through which the blood, owing to friction, escapes with difficulty into the capillaries.

If while continuing to work the syringe you make a small hole in the rubber tube, the water will spurt out, and the harder you pump the higher will it spurt in proportion as the pressure of the fluid within becomes greater. To measure the pressure you must obtain a glass tube shaped like ⊥, and, dividing the long rubber tube, connect the divided ends again by means of the horizontal limb of the ⊥ tube. To the vertical limb a glass tube 2 to 3 feet long must be joined. On now pumping the syringe the water will rise in the vertical limb of the tube

to a certain height, and this height will indicate the pressure within the rubber tube. Say the water rises three feet, then the pressure is sufficient to support a column of water three feet high.

Now carefully notice the following points:—

(1) On pumping harder the pressure rises.

(2) On pumping less forcibly the pressure falls.

(3) While pumping as steadily and uniformly as possible, the pressure falls if the exit from the rubber tube be opened, rises if the exit be narrowed.

(4) At the same time that the pressure falls when the exit is opened, more water flows out from the tube; conversely, much less water flows out from the tube when the exit is narrowed, and at the same time the pressure rises. The outflow during each minute can be measured with a measure-glass.

(5) When the exit is open the flow is intermittent (in spurts). When the exit is narrow the flow is more continuous.

(6) When the exit is open the force of your hand is expended in making the water flow. When the exit is narrow a great part of the force is expended in expanding the elastic tube so as to drive the water within it. In the latter case the elastic force of the tube pushes the water on and makes the flow continue during the intervals between each stroke of the pump.

Measurement of blood pressure. About 150 years ago Stephen Hales, a country clergyman, placed a ⊥ tube in the artery of a horse, and, connecting this with a long vertical glass tube, found that the blood rose to a height of about eight feet and there oscillated up and down with each systole and diastole of the heart. He thus proved that the heart of a horse can at each systole lift a column of blood eight feet high.

It is more convenient to use a U-shaped tube containing mercury. This is 13½ times as heavy as water and therefore the column of mercury need only be about six inches high. A little float carrying a straw and writing style can be put on the mercury, and a record taken of the oscillations on a drum covered with smoked paper.

The heart of a man can lift a column of blood about five feet high (a metre and a half). The pressure can be measured very easily by an instrument called a *sphyg-*

mometer. This consists of a broad rubber bag enclosed in a leathern armlet. The armlet is strapped round the arm above the elbow. The rubber bag is connected with a pressure gauge, and with a syringe-bulb. The pressure is raised in the bag by pumping air into it.

When the pressure exerted by the sphygmometer on the outside of the artery equals the mean pressure of the blood within the artery, the wall of the artery gives with each heart-beat its biggest jog to the fluid within the sphygmometer. The height of the mercury is read on the scale at the point where the greatest pulse is observed, and this tells us the blood pressure [1].

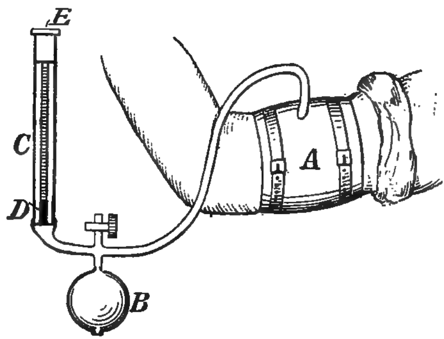


FIG. 80. Sphygmometer. A. Armlet. B. Syringe-bulb. C. Gauge. The fluid meniscus D rises in C with the pressure, compressing the air above it. The air acts as a spring to the gauge. E. Screw-top for adjusting the meniscus to the zero mark.

The average pressure in the arteries of a healthy man at rest is sufficient to support a column of mercury 100 mm. high (4 inches). Mercury is $13\frac{1}{2}$ times as heavy as blood, so the pressure would lift a column of blood about $4\frac{1}{2}$ feet high. The pressure becomes higher, owing to the increased action of the heart, when a man is at work.

In contrast with the blood pressure in the arteries that in the veins is usually very little. If the veins on the arm be emptied upwards it takes very little pressure of the sphygmometer to stop them filling again, say about

[1] Another way, and perhaps the best, is to find the pressure which stops the pulse coming through to the radial artery.

one-tenth of the pressure found within the radial artery. The pressure in the capillaries is slightly more than that in the veins.

The cause of the difference of blood pressure in arteries and veins. We must now consider why the pressure is greatest in the arteries, and becomes less in the capillaries, and least in the veins.

Suppose, in place of the basin of water, you connect together the open end of the bulb syringe and the narrowed orifice of the rubber tube by means of a wide-bored flaccid tube, such as a sausage-skin, and let this contain water. On working the syringe, water will be sucked out of the sausage-skin into the syringe at each diastole, and driven out of the syringe and through the rubber tube at each systole; from whence it will escape back into the sausage-skin. The water can only circulate in this direction owing to the valves in the syringe.

In this model the sausage-skin represents a vein, the rubber tube an artery, the narrowed orifice of the rubber tube the small arteries; for at this point friction obstructs the flow from the artery into the vein. When the syringe is at rest and the model lies flat on the table the pressure of the fluid will be the same in all its parts. On squeezing the syringe, fluid is sucked from the vein and forced into the artery faster than it can escape back into the vein. Thus the artery becomes distended, and the pressure of the water rises within the artery. On ceasing to squeeze, the elastic force of the distended artery continues to press the water on through the orifice and back into the vein, until finally the pressure again becomes the same in all parts of the model and the flow ceases. Now you know energy cannot be destroyed, but can only be changed into some other form. The energy of your muscles, expended in squeezing the syringe, and at first stored up as elastic force in the distended artery, is finally spent in driving the fluid through the narrowed orifice of the artery, i.e. in overcoming friction. It is in fact turned into heat, just as the movement of a train is turned into heat when the brake is suddenly applied and sparks fly.

In the circulation of the living animal the conditions

are just the same. The heart pumps blood from the veins into the aorta and its branches, and distends their elastic walls; for the blood cannot easily escape into the veins because of the friction which opposes the flow in the small arteries. In overcoming this friction energy is turned into heat, and thus the pressure produced by the heart is mostly dissipated into heat in the small arteries. This heat helps to warm the body. The duty of the heart is to force the blood into the arteries, whence it is driven continuously through the capillaries. When this end has been attained the force is almost entirely expended, and we see this is so by the fact that the pressure in the capillaries and veins is very much less than that in the arteries. *It is this difference of pressure which causes the blood to flow through the capillaries.* The blood is returned to the heart through the veins, not so much by the propelling force of the heart as by other mechanisms, which we must now discuss.

The influence of posture and movement on the circulation. Hang up the model in the vertical position with the syringe at the top, and work the pump; your efforts will be of no value, for the water in the flaccid sausage-skin will, owing to its weight, seek the lowest level; thus there will be none at the top from which to fill the heart. By squeezing the sausage-skin from below upwards, you can however raise the water to the pump, and so long as you do this the circulation can be maintained.

When a grass-snake is held extended in the vertical position (head up) the veins of its body are so easily distended by the weight of the blood that the heart empties and all the blood sinks towards the tail. If the body be squeezed upwards, the heart again fills and the circulation continues. In a tame rabbit with a big flaccid abdomen the same thing may happen, and the animal may be killed if it be held up by its front paws for too long a time.

Unlike the snake or rabbit, man naturally walks erect; his skin is therefore taut and elastic and he is active in all his movements, his veins are kept confined, and the blood is not allowed to settle down within them. Bare your arm and hold it motionless for some minutes in the dependent posture. The veins will become more and more swollen. Raise the arm into the vertical position, and the veins immediately empty and disappear from view. It is obvious from this that change of posture affects the flow of blood in the veins. Once more hang the arm down until the veins become congested; then, still holding the arm dependent, forcibly and several times in succession clench your fist. The contractions of the muscles squeeze the veins, for they lie confined within the taut skin, and, owing to the valves in the veins, the blood is thereby driven on towards the heart. For a third time hang the arm dependent, and then stroke the limb upwards with the other hand; by this action the veins are emptied. Now we continually shift our posture, contract our muscles, and press our bodies against outside objects, and all these acts contribute towards maintaining the flow of blood from the dependent veins towards the heart. If we hold a limb in one position, or sit in the same position for long, owing to a feeling of numbness, we become uncomfortable and therefore move. To stand perfectly stationary in a crowd is likewise very fatiguing. In these cases the blood congests in the dependent veins and the circulation becomes less efficient. Soldiers, for this reason, are best not kept standing at attention for long, but must be told to beat time with their feet[1].

Influence of respiration on the circulation. Each respiration also aids in the return of blood from the veins, and in this wise—the heart and lungs lie within

[1] The author knew of a school where the girls stood for 15 minutes at prayers. Rarely a day passed without one going out of the room faint.

the thorax; in inspiration, the thorax is raised and becomes larger, and its contents are expanded, while the diaphragm, by contracting, descends and compresses the abdomen; in expiration, the thorax becomes smaller and its contents compressed, while the diaphragm rises up again. Now in inspiration, the compression of the abdomen will squeeze blood from the large veins of the intestines and liver up into the right side of the heart; at the same time the expansion of the thorax will not only cause air to be sucked into the lungs through the windpipe, but will also cause blood to be sucked from the venae cavae into the right side of the heart. On the other hand, in expiration, the compression of the thorax will not only drive air out of the lungs, but will at the same time render the entry of blood into the right side of the heart more difficult. Then again, in inspiration, as the lungs become expanded, they hold more blood; while in expiration, as they are compressed, a good deal of blood is driven out of the lungs into the left side of the heart.

Owing to all these facts the respiratory pump is of great aid to the heart, furthering not only the return of venous blood, but also the circulation through the lungs.

You can easily see the effect of respiration on the veins in a man seized with a violent fit of coughing. The veins and capillaries of his face become congested, and his face reddens. Under these conditions the obstacle to the entry of blood into the heart is very great, for the pressure within the thorax becomes so high during each cough that blood can scarcely enter the right auricle, while the flow through the lungs is obstructed.

If a man be crucified or strapped to a tree in the vertical position he dies eventually, as the blood, owing to its weight, slowly congests in the veins in the lower part of his body. At first the circulation is maintained, for he can

to a certain extent contract his muscles, although he cannot move his limbs; moreover, he can by respiration lift up the blood from the abdominal veins into the heart. As the sufferer becomes exhausted with cold, hunger, and pain, his muscles become limp, his skin flaccid, and his respiration feeble; the veins are no longer confined and compressed, and hence the blood not only settles down within their roomy reservoirs, but the fluid part escapes through the capillaries into the tissues. Thus the legs and abdomen swell, the heart fails to obtain blood from the veins, and the man dies so soon as the circulation through his brain ceases.

The importance of muscular exercise. From the above discussion it becomes clear how great must be the value of active exercise, walking, running, rowing, bicycling, swimming, gymnastics, &c. Without exercise a man cannot maintain an active circulation through his brain or body. It is from neglect of exercise and interesting employment that men and women surrounded with wealth, and who are brought up to do nothing useful, suffer from hysteria and nervous debility, and become a worry to their friends. There is no lesson which more requires to be *re-learnt* by man, for it was known to the ancient Greeks: *healthy mental development cannot advance without muscular development.* Let the indolent woman and the hard-worked sempstress scrub floors, and the lazy man or hard-worked scholar dig the ground for two hours a day, and half the medical profession would starve for lack of patients.

When the skin loses its tone and hangs flaccid, when the abdomen is large and lax, and the muscles feeble, the blood tends to stagnate in the lower parts. Debilitated men wear abdominal belts to gain artificial support. They strap india-rubber bandages round their legs to prevent varicose veins. They go to bathing-places and sit for hours up to their neck in water, and this aids their circulation,

for the pressure of the water on the skin prevents the congestion of the veins. It were much better if they worked hard to develop the muscles and the elasticity of the skin.

Summary of the facts discussed in this chapter.

1. The heart is an intermittent pump.

2. The great arteries are essentially elastic tubes.

3. The small arteries are essentially muscular tubes.

4. Owing to the fact that the blood cannot escape easily through the small arteries, the large arteries are kept distended by the systoles of the heart.

5. The elasticity of the distended large arteries continues to force the blood on through the small arteries during the diastoles of the heart. Thus an intermittent flow from the heart is converted into a continuous flow through the capillaries.

6. The force of the heart is mostly expended in driving the blood through the small arteries, and, owing to friction, it is dissipated into heat. The blood pressure is high in the arteries, much less in the capillaries, and least in the veins.

7. The blood is returned from the veins to the heart mainly by the action of the muscles, by constant change of posture, and by the aid of the respiratory pump.

8. The veins are wider than the arteries. They are provided with valves, but are neither very muscular nor very elastic.

9. The capillaries have exceedingly thin walls through which the exchange between the blood and tissue-cells takes place.

CHAPTER XXII

THE CIRCULATION OF THE BLOOD (*continued*).

The pulse. By the expulsion of the blood at each systole, the walls of the aorta are suddenly distended. From the aorta a wave of distension ripples down the walls of the arteries. This wave of distension, which can be felt in all the large arteries, is called the pulse. As the wave is distributed over all the small arteries, it becomes too small to be perceptible there, and disappears. If an artery be wounded the blood does not flow continuously, but is jerked out more forcibly with each pulse.

You can imitate the production of the pulse exactly with the help of the syringe and model constructed for studying the general principles of the circulation. With each squeeze of the syringe, a pulse can be felt in the rubber tube.

The wave of distension or pulse travels much more rapidly than the blood; in the time that the blood occupies in flowing one inch down an artery, the wave will have rippled over eighteen inches. In about one-eighth of a second the pulse wave travels from the arch of the aorta to the wrist, while the blood will occupy two or three seconds in travelling the same distance.

Similarly, if a stream be flowing steadily along, and you cast therein a stone, a wave ripples over the stream, and this wave travels at a rate quite different to that at

which the stream is flowing. By feeling the pulse with the finger, it can be determined whether the heart-beat is frequent or infrequent, strong or weak, regular or irregular; thus the pulse is an important guide, for it tells us the condition of the heart. The condition of the arterial wall and the blood pressure in the arteries can likewise be determined by the examination of the pulse.

The work of the heart. It has been determined that the left ventricle throws out into the aorta about three ounces of blood during each systole. The blood is forced into the aorta by a pressure which is sufficient to just lift a column of blood five feet in height. The work done by the left ventricle is thus the same as that which you would expend in throwing a three-ounce weight five feet up in the air, or in lifting fifteen ounces up one foot. The right ventricle also expels three ounces of blood at each systole, but it does not exert so great a pressure, for the blood can be driven more easily through the lungs than through the rest of the body. The work of the right ventricle is about one-third that of the left; it would be equal to the work you would expend in lifting five ounces up one foot.

The total work of the two ventricles is, then, equivalent to a lift of $15 + 5 = 20$ ounces up one foot.

Now the heart beats seventy times a minute, and there are sixty minutes in an hour and twenty-four hours in the day, so the work performed by the heart during one day is equivalent to $20 \times 70 \times 60 \times 24 = 2{,}016{,}000$ ounces, or 126,000 pounds lifted up one foot. This total can be represented as the amount of work which a man of average weight (say about 150 pounds) would do in running up a flight of forty steps forty times.

The heart muscle is able, day by day, to do this great

amount of work, owing to the fact that it alternately works and rests, and is, at the same time, well supplied with blood by means of the coronary arteries. Similarly, at a certain rate of work, alternating with rest, the muscles of a man can be made to work, as in bicycling, without fatigue for a great many hours. If he lift too heavy a weight, or the work be done too quickly, fatigue rapidly ensues, for the contractile substance is then expended more quickly than it is repaired. So is it with the muscle of the heart.

A man out of training soon becomes blown and spent if he attempts any prolonged muscular effort, for his heart is unable to maintain a sufficiently rapid circulation and meet the demands of the skeletal muscles for more blood. The heart, like the muscles, grows stronger with exercise.

The velocity of the blood-flow. A river flowing through a narrow gorge runs fast and impetuously on its course; it slackens so soon as it reaches the plains and spreads out into a great number of streams. If the river again enter a gorge, the flow becomes once more fast and impetuous. So is it with the blood-flow. In the aorta, the channel is narrow and the flow fast; through the capillaries, the blood moves slowly, for here the total bed through which the stream flows is far wider than that afforded by the aorta. As the capillaries join into veins, and the smaller veins join into larger veins, the bed becomes again narrowed; finally in the two venae cavae the capacity is not much greater than that of the aorta.

In the aorta, the blood has been estimated to flow at the rate of about 350 mm. (about fifteen inches) a second; in the capillaries, the blood does not move more than the diameter of a pin's head in one second. In the venae cavae the flow is about ten inches per second.

The circulation time. If some of the poison strychnine

be put into a vein, it will reach the spinal cord in about twenty seconds, and cause convulsions. It takes only this short time for the blood conveying the poison to pass from the veins to the right heart, through the lungs to the left heart, and from thence along the aorta to the capillaries of the spinal cord.

It follows from this that when a man is bitten by a poisonous snake in the leg, a cord must be tied round the thigh with the greatest rapidity so as to stop the circulation, if the poison is to be prevented from reaching the rest of the circulation. If a large artery be severed, the part next the heart must likewise be very rapidly compressed, otherwise the heart will expel the blood through the opening with such velocity that the man will in one or two minutes be dead.

Nervous control of the circulation. Think of the water supply of a town. There is the pump at the reservoir, the main pipes in the streets, and all the little pipes ending in taps in the houses. If every householder opened every tap at once, the demand would be greater than the supply. It is owing to the fact that most of the taps in the houses are at any one time turned off, that each individual can get a good supply by opening his own tap.

Suppose a fire to arise in a street, and a great deal of water be required there. The water-man can in this case turn off the mains in the other streets so that more water may come to the fire-engines; at the same time, the engineer may increase the force of the pump at the reservoir.

If there be nobody dwelling in a house and no water is required, the water-man cuts off the supply to that house. If the town become to a considerable extent emptied of people, and less water be required, the pump can then be worked at a slower rate, and less forcibly.

So is it with the circulation of the blood. Not all the

organs of the body are in activity at the same time, but those which are at work require plenty of blood. The muscular coats of the small arteries act as taps, for by means of the muscle the arteries can be constricted or dilated.

Vaso-motor nerves. There are fine nerves, known as vaso-motor nerves, running along the course of the arteries and ending in a network of filaments in contact with the muscle-cells. These nerves arise from the anterior roots of the spinal nerves, and thus have their origin in the spinal cord. There are two kinds of vaso-motor nerves, *vaso-dilator* and *vaso-constrictor.* All the vaso-constrictor nerves arise from the nerves which issue from the spinal cord in the thoracic region. From thence they pass to a chain of *ganglia* (called *sympathetic*) lying along the front of the vertebral column. The ganglia are little masses of nerve-cells with which the vaso-constrictor and visceral nerves are connected, and from these cells there pass the fibres which ultimately run along the walls of the arteries.

There are vaso-dilator nerve-fibres in most of the cranial and spinal nerves. These fibres do not pass into the sympathetic chain of ganglia, but run to all parts of the body in the common nerve-trunks, from whence they reach the walls of the arteries.

At the point where the spinal cord begins to swell out to form the brain in what is called the spinal bulb or medulla oblongata there is situated the *vaso-motor centre,* that is, a group of nerve-cells and fibres with the existence of which there is bound up the control of the small arteries.

From the vaso-motor centre, impulses are continually discharged along the vaso-constrictor nerve-fibres. These keep the small arteries in a state of constriction, and limit the flow of blood. If this part of the brain be irritated,

the small arteries all over the body constrict, and while the pressure in the arteries rises, the flow diminishes, for the outlets through which the blood escapes into the capillaries become narrowed. If, on the other hand, the vaso-motor centre be destroyed, and its influence abolished, all the small arteries dilate. The blood then runs into the veins almost as quickly as the heart pumps it into the aorta. In this condition there is scarcely any pressure in the aorta during diastole, and the flow into the capillaries is no longer continuous, but intermittent. Moreover, there is not enough blood to fill all the dilated vessels, and the blood, owing to its weight, tends to drop into the vessels which are lowest. Thus, if the vaso-constrictor nerves cease to act in a man who is standing in the vertical position, he will faint, for the blood runs down into the dilated vessels of his abdomen, and not up to his brain. In order that the brain may obtain a good supply of arterial blood, it is necessary that the small arteries in the intestines and other abdominal organs should be kept constricted. Whenever the brain requires more blood, the vaso-motor centre, by causing constriction of the abdominal vessels, turns off, as it were, the taps to these parts. On the other hand, during the digestion of a dinner, the abdominal organs require more blood, and, in consequence, the brain obtains less. Therefore 'after dinner rest awhile.' When the skeletal muscles are in activity they require more blood, and this they obtain by the action of the vaso-dilator nerves which supply the arteries. In consequence less blood must go through the abdominal arteries, and these are kept constricted. On a hot day the skin is flushed with blood, in order that the body may be cooled by radiation and evaporation. On a cool day the opposite condition exists, and the blood is, as far as possible, kept within the viscera. The arteries of the skin are controlled by vaso-motor nerves.

If you look at a rabbit's ear on a hot day, or when the animal is warm before a fire, you will see numberless little blood-vessels forming a close network all over the ear. Take the animal into the cold, and these vessels will soon constrict and disappear.

If the nerve in the neck called the *cervical sympathetic* be divided the vessels of the ear dilate, and the ear blushes, and becomes warm. But if this nerve be excited by electric shocks the vessels shrink up, and the ear becomes pale and cold.

Emotions affect the vaso-motor nerves: blushing is an excellent example of vaso-dilatation, while sudden fear produces pallor and constriction of the blood-vessels. You learn from these facts how much the colour of the face depends on the blood. A healthy complexion depends upon a healthy circulation.

The cardiac nerves. In discussing the water-works of a town we determined that not only the taps but the pump could be controlled. So too the heart is under control of the nervous system. Running down the neck close to the carotid artery, on either side, there lies a fine white cord, the *vagus* nerve. This may be seen by dissection in the rabbit. The vagus nerves arise from the spinal bulb, and are there controlled by a centre (*cardio-inhibitory centre*) which lies next to the vaso-motor centre.

The vagus nerves send fibres to the larynx, gullet, lungs, and stomach, but the fibres which concern us now are those that pass to the heart.

The grass-snake possesses vagus nerves, and if one of these be stimulated in the decapitated animal, the heart of a sudden ceases to beat. The same thing would happen if either vagus were stimulated in a man immediately after his head has been struck off by the guillotine.

The vagus nerves contain nerve-fibres (*inhibitory*) by which the heart can be made to beat more slowly, or stopped for a short time altogether; the centre of the vagus nerves in

the brain is always acting, keeping a bridle action over the heart and regulating the rate of its beat according to the needs of the body. Thus the heart beats faster in times of muscular exertion, but more slowly during rest and sleep. From the sympathetic ganglia at the root of the neck there passes to the heart another set of nerve-fibres. These have their origin, like the vaso-constrictor nerves, from the nerves which issue from the thoracic region of the spinal cord. On exciting these nerves (*acceleratory* and *augmentory*) the heart beats faster and more forcibly, so their influence is exactly the opposite to that of the vagi.

There are, in addition to the above, some very curious nerve-fibres which arise in the heart and pass *up* to the spinal bulb. In part of their course the fibres ascend in the vagus nerves. On separating these from either vagus and applying a stimulus, the vaso-motor centre in the spinal bulb is influenced in such a way that the small arteries all over the body dilate. Thereupon the blood escapes more easily into the capillaries, and the heart, owing to the consequent fall of pressure in the aorta, expels the blood at each systole with less effort. By means of this nerve (*the depressor*) the heart can 'open the floodgates' when feeling strained, and obtain relief.

Thus you see the brain possesses complete nervous control over the circulation. By its means the pump can be made to work quickly or slowly, and each organ can obtain the blood it requires during activity or rest. By its means also the heart can find relief from overstrain.

So perfect is the adjustment of the circulation carried out by our brain, that from day to day the pressure of blood in the arteries remains constantly at the same height. At the same time, as the messages which stream to and from the centre in the medulla oblongata do not enter into our consciousness, the child or untutored savage is innocent of the existence of either his heart or blood-vessels.

CHAPTER XXIII

RESPIRATION.

OXYGEN must be supplied to protoplasm in order that the energy of life may continue to be made manifest. Such minute organisms as the amoeba and the hydra live bathed with water which contains oxygen in solution. The bodies of insects are traversed by minute tubes which convey air from the outside to each cell of the organs seated within. In the larger bodies of the higher animals, some other and more convenient method of supply is required. In these the tissues depend upon the circulation of the blood, and in particular on the special oxygen carriers, the red corpuscles. Not only does the blood bring food and oxygen to the cells, but, by its means, carbon dioxide and the other waste products of cell life are borne away. In one part of the body of the higher animals there are developed special structures, gills or lungs, whereby the blood is exposed in a thin sheet either to water containing air in solution, or to the air itself. In these organs the red corpuscles, robbed of oxygen by the tissues, straightway load themselves afresh, while at the same time carbon dioxide is expelled from the blood-plasma.

Fishes and other water animals possess gills. By means of these organs water is rhythmically swept over thin membranous sheets of tissue which contain networks of capillaries full of blood. It is easy to observe the action of the gills in live eels.

The grass-snake possesses a long bag, the walls of which are pitted like the cells of a honeycomb. Into this opens the windpipe, and the animal, by contracting and expanding its body rhythmically, pumps air in and out of its lung. In the walls of the honeycomb there lies a close network of capillaries. In both eel and snake, to obtain sufficient exposure, the vascular tissue is thrown into folds.

Birds possess, in addition to small lungs, extraordinarily large and membranous air-sacs. The sacs surround the lungs and extend between the organs of the body. They are connected both with branches of the windpipe and with the hollow medullary canals of the bones. Thus a bird can continue to breathe through a broken humerus when its windpipe is closed. The air-sacs in the bird act like the bags of a bagpipe, and carry the air required for song. The air-sacs are expanded by the action of muscles at each inspiration and compressed at each expiration. Air is thus driven in and out of the lungs and windpipe.

In man and other mammals the folding of the lungs is carried to the greatest extreme. It is estimated, supposing the lungs of man to be unravelled, that the vascular sheet of membrane would, when spread out flat, cover an area of 100 sq. yds. Measure a square on the ground ten yards each way; the blood is exposed to the air in your lungs over a corresponding area. Nevertheless, these organs, owing to the principle of their structure, are not only packed away in the body within a small space, but are completely protected from injury. The surface of the 25 million million red corpuscles which circulate, would cover an area of nearly 3,500 sq. yds., so no wonder we can get plenty of oxygen.

The structure of the air-passages. The nose. Man naturally breathes through his nose; and this is important,

for the air is not only warmed and rendered moist therein, but is filtered free of bacteria during its through passage. Moreover, the sense of smell gives us warning of the existence of noxious vapours. From the sides of the nasal passages project the scroll-like bones; these are covered, like the rest of the nasal cavity, with soft *mucous membrane*. This consists of a soft pad of connective tissue containing a network of blood-vessels and numberless little mucous glands, and lined on the surface by a layer of ciliated epithelium. The structure of the nose can be studied in a sheep's head which has been sawn in half by the butcher. When, owing to the growth of bacteria, the mucous membrane becomes swollen and inflamed, the discharge from the mucous glands becomes greatly increased. Under such conditions a person is said to have a cold in the head. This is of no great moment, so long as the bacteria are limited to the nose, and do not invade the windpipe and lungs. An infant cannot suck properly if its nose be choked with a cold, for it cannot both suck and breathe through its mouth at the same time. It is the lower and middle portion of the nose through which the air passes. At the top of the nose there lies the special olfactory organ. All the air-passages are lined with ciliated cells. These are long and columnar in shape, and are set with fine vibratile filaments which continually lash to and fro.

Ciliated cells. Ciliated cells can easily be obtained by scraping the roof of the mouth of a decapitated frog. On mounting the scrapings on a glass slide and examining them with the microscope (high power), you will see clumps of cells, or single cells, with the cilia in active movement. The gill-bars of the common mussel are lined with cilia, which lash the water over the bars in a continuous stream.

With a little trouble you can carry out the following interesting experiment:—Place a small ring of putty on a glass

slide. Leave a gap in the ring at one point. Mount on a cover-slip some ciliated cells of the frog, or a gill-bar of the mussel. Place the cover-slip face downwards on the putty ring so that the cells lie within the moist chamber thus formed. Now observe under the microscope that the cilia are actively working. Push within the chamber a bit of ice. The cilia exposed to cold will lash more slowly. Replace the ice with warm water, heated to a temperature which your hand can bear comfortably. The cilia will then lash very quickly. Finally

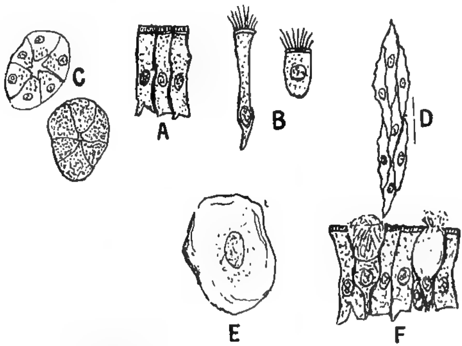


FIG. 81. Microscope, high power. Types of cells. A. Columnar-shaped cells which line the intestine. B. Ciliated cells which line the air-tubes. C. Gland-cells; resting, full of granules; after activity, shrunk and few granules. D. Thin, spindle-shaped, scaly cells such as line the blood-vessels. E. Scaly cell from inside of mouth. F. Columnar cells of intestine showing two mucous or goblet cells.

replace the warm water with a few drops of chloroform water (to be obtained from the druggist); the cilia will quickly cease to move. The movement of the cilia covering a membrane resembles that of a field of corn under a gust of wind. Each cilium bows its head in turn and drives the fluid onwards. If you place a tiny bit of cork on the upper surface of a frog's mouth, the cork will be slowly swept by the cilia towards the gullet: you can time how long the cork takes to move a certain distance when the membrane is moistened either with iced or with warm water.

The trachea and bronchial tubes. From the nose the air passes into the pharynx. At its lower end the pharynx

ends in two tubes. Behind lies the *oesophagus*, the walls of which remain collapsed except during swallowing, while the windpipe or trachea is set in front. The trachea is supported by stiff rings of cartilage, and always remains open; the oesophagus, on the other hand, is a flaccid tube. At the top of the trachea is the larynx, a cartilaginous box in which the voice is produced.

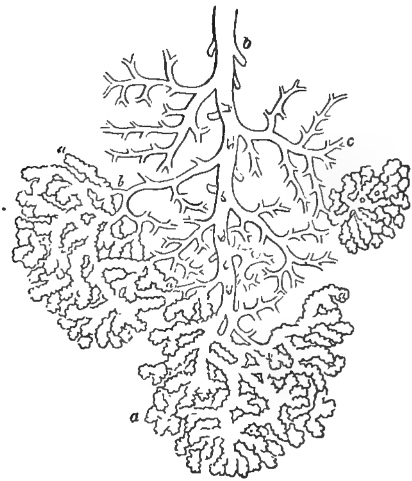


FIG. 82. Lung. Diagram showing how an air-tube branches and ends in air-sacs. *a.* Air-sacs. *b.* Bronchial tube. *c.* Little bronchial tubes.

Obtain from the butcher the lungs and windpipe of a sheep, including the larynx. At the top of the larynx and the root of the tongue there lies the *epiglottis*. This is a lid-like structure formed of yellow elastic cartilage within, and covered with mucous membrane without.

Looking within the larynx, you can see a narrow chink, the *glottis*, through which the air passes into the trachea. The chink is bounded on either side by the two membranous vocal cords, each of which is set like the reed in a whistle.

On swallowing, the larynx can be felt to move upwards; it thus rises against the epiglottis, for this is at the same time pressed down by the root of the tongue. The opening into the larynx being closed, the food is prevented from passing into the lungs, while it glides over the epiglottis into the gullet. If, by any chance, any particle of food does fall within, the sensory nerve-endings in the mucous mem-

brane of the larynx are excited, and a violent cough is produced, by which the substance is expelled. A substance drawn by accident into the lungs, such as a pea from a pea-shooter, may set up dangerous inflammation of the lungs.

Cut off the larynx from the trachea, and keep it in a bottle containing some methylated spirit for further examination.

Examine the trachea. It is formed of C-shaped rings of cartilage covered within by mucous membrane; the rings are incomplete behind where the trachea rests upon the gullet, which in its turn lies flattened against the vertebral column. Owing to the rings of cartilage the trachea remains always open, and cannot, except by considerable force, be compressed.

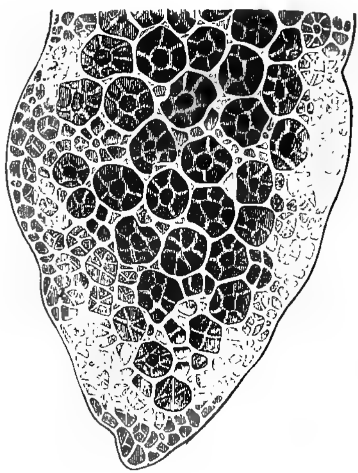


FIG. 83. A piece of lung which has been distended with air, dried, and then cut open. The honeycomb structure of the air-sacs is shown.

The imperfect rings of cartilage embedded in, and joined to each other by connective tissue, are completed behind by a band of spindle-shaped non-striated muscle-cells. The mucous membrane is lined with ciliated cells resting on a soft vascular bed of connective tissue in which lie small glands that secrete mucus. The mucous membrane is kept smooth and free from wrinkles by the presence of a layer of elastic fibres lying beneath the ciliated epithelium. Below, the trachea divides into the two *bronchi* of similar structure. Each bronchus diving into a lung divides again and again into

numberless bronchial tubes, which pass to all parts of the lung, and end finally in air-sacs.

The structure of the lung. The lung is constructed on the same principle as a bunch of grapes: there is the main stalk (the trachea), the numerous branches and sub-branches (the bronchial tubes), and the grapes (air-sacs) at the end of every little branch. But in the lung the subdivision is carried to such a degree that the air-sacs and

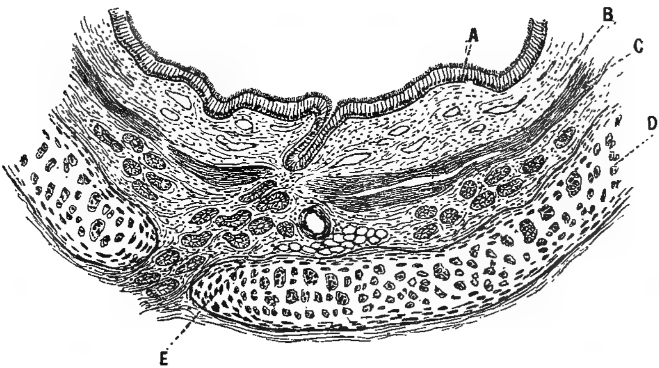


FIG. 84. Microscope, low power. Section through a piece of the wall of a large bronchial tube. A. Ciliated cells. B. Soft, connective tissue; the holes in this are blood-vessels. C. Layer of non-striped muscle. D. Cartilage stiffening the wall. E. Mucous gland.

small bronchial tubes can only be seen with the microscope. Moreover, each air-sac has a honeycombed wall, and thus contains a number of *air-cells.*

Slit open the trachea with scissors, and thence cut along one bronchus into the substance of the lung so as to follow as far as possible the subdivisions of the bronchial tubes.

The larger bronchial tubes have small lumps of cartilage scattered in their walls. They are lined with a mucous membrane containing mucous glands and covered with ciliated cells. These cells, by lashing their cilia, continually

drive mucus up to the mouth, and so cleanse the lungs of dust and bacteria. There is a complete ring of spindle-shaped muscle-cells surrounding the bronchial tubes. Fibres in the vagus nerves pass to this muscular coat, and may, if excited, cause the bronchial tubes to contract. As the smallest subdivisions of the bronchial tubes open into the

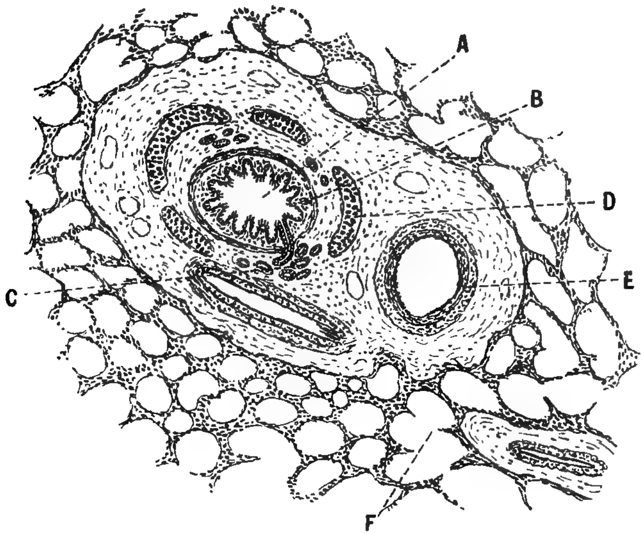


FIG. 85. Microscope, low power. Section through a fragment of the lung. A. Bronchial tube lined with ciliated cells. B. Layer of unstriped muscle. C. Mucous gland with duct. D. Cartilage stiffening the walls. E. Branch of pulmonary artery. F. Air-cells in which the bronchial tubes end.

air-sacs, the epithelium ceases to be ciliated, and becomes flattened, while the muscular coat disappears. The air-sacs, and the air-cells within them are lined with flat pavement cells. These are supported on the outside by elastic fibres and white fibrous tissue, which bind the air-sacs together into lobules, the lobules into lobes, and the lobes into the whole lung. Everywhere the lung is permeated with elastic fibres.

Pass a tube into the uninjured bronchus of the lung which you have not dissected, and blow down it. The lung expands like a balloon, and collapses again when you cease to blow, owing to its elasticity.

How important this property of elasticity is, you will see in studying the mechanism of respiration.

The pulmonary circulation. The pulmonary artery brings blue venous blood from the right ventricle to the lungs. It divides into branches which pass to the lobes and lobules, and which finally end in a network of capillaries running over the wall of each air-sac and up in the partitions which divide the honeycomb like air-cells. Separating the blood in the capillaries from the air in the air-cells there is nothing but the thinnest of membranes, composed of two layers of flat pavement cells—one of these lines the air-cells, the other forms the capillary wall. Through this membrane the exchange of gases takes place. The pulmonary veins gather up the blood from the capillaries and return it as bright red arterial blood to the left side of the heart. The change in colour is brought about by the combination of oxygen with the red colouring matter of

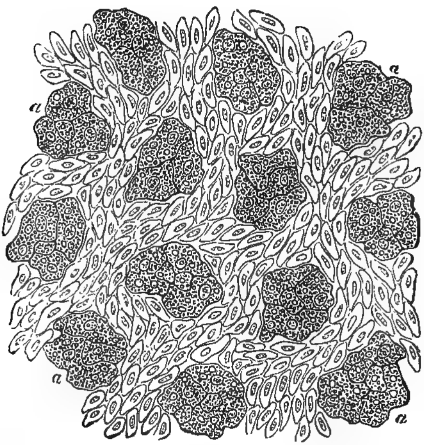


FIG. 86. Microscope, high power. Wall of an air-cell of a frog's lung, showing capillaries full of red blood corpuscles and (*a*) pulmonary epithelium.

the blood. Oxy-haemoglobin is bright and scarlet, while reduced haemoglobin is bluish and dark in colour. In the tissues the oxygen is taken from the haemoglobin; in the lungs it is restored. The carbon dioxide is carried partly by the corpuscles, and chiefly by the salts in the plasma. It in no way affects the colour of the blood. In order that the blood may continually acquire oxygen and yield up carbon dioxide, it is necessary that the air in the lungs should be renewed. This is effected by the act of respiration, which occurs about fifteen to eighteen times a minute.

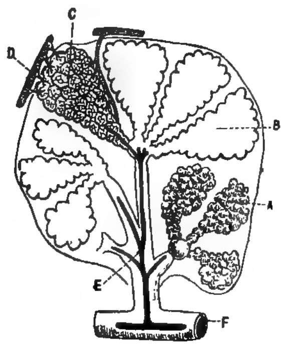


FIG. 87. Model of a lobule of the lung. A. An air-sac and air-cells. B. An air-sac cut open. C. Capillary network over an air-sac. D. Branch of pulmonary artery. E. Branch of pulmonary vein. F. Bronchial tube. After Testut.

The thoracic cavity and the pleura. The lungs and heart, the roots of the great blood-vessels, and the whole of the blood-vessels of the lungs, lie within the thoracic cavity. The thorax is formed of a bony cage, ribs, spine, and sternum. Filling up the spaces between the ribs lie thin sheets of muscle (the *intercostal muscles*). These are covered on the outside by the skin, within by a thin glistening membrane (the *pleura*). The pleura is constructed like the pericardium, and just as this membrane both forms the heart-purse and covers the heart, so the pleura not only lines the inner wall of the thorax, but passing on to the roots of the lung where the pulmonary vessels enter, thence courses over the whole surface of the lungs. The pleura is moistened with a fluid which acts as a lubricant and allows the lungs to glide over the inner wall of the thorax without friction. If the pleura become inflamed, as in pleurisy, its surface becomes sticky and

rough; the lung may even adhere to the wall of the thorax, and so be restricted in its movement. The thoracic cavity is divided into a right and left chamber by the heart and the fibrous tissue which holds the heart in its place. Each chamber contains a lung, and is, owing to the nature of its walls, absolutely air-tight. Below, the thoracic cavity is bounded by the dome-shaped muscular partition, the

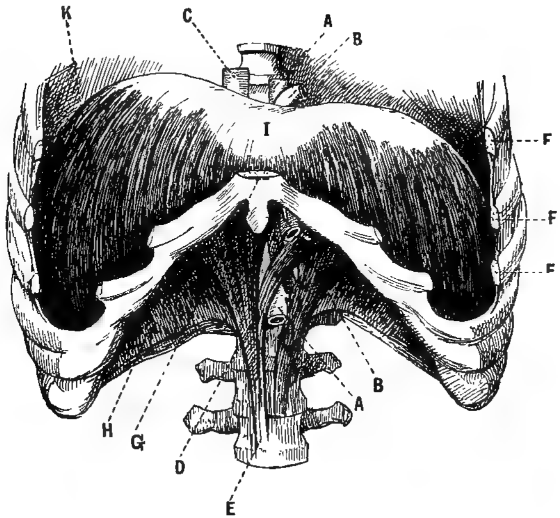


FIG. 88. The dome-shaped diaphragm. A. Aorta. B. Oesophagus. C. Vena cava inferior. D. Muscular pillars of the diaphragm arising from the spinal column E. F. Ribs, and G sternum, sawn through so as to allow removal of the front of the thorax. H. Hind, and K front muscular sheet, and I central tendinous part of diaphragm.

diaphragm. To the bony cage of the thorax many muscles are attached, such as the pectoral muscles passing to the arm, the neck muscles passing from the upper ribs to the head and cervical vertebrae. At the back are muscles passing to the shoulder-blade and to the spine, and below, the thin sheets of muscle which pass to the hip-bones and form the wall of the abdomen.

The act of respiration. The thoracic cavity can be enlarged in two ways: firstly, by the contraction and consequent descent of the diaphragm; secondly, by the elevation of the ribs. At each inspiration, both these acts occur. The central tendon of the diaphragm remains fixed, while the dome-shaped muscular part, which forms the floor of each pleural cavity, contracts. By the descent of the diaphragm the abdominal organs are compressed. Draw a deep breath, and you will feel your abdomen swell out. The abdominal wall is elastic; thus, when the diaphragm ceases to contract, it is again driven upwards into the arched position by the elastic recoil of the abdominal wall. This takes place at each expiration. Since the diaphragm is attached to the lower ribs, it would, on contracting, pull these inwards, were it not for the action of antagonistic muscles in the back, which draw the same ribs outwards.

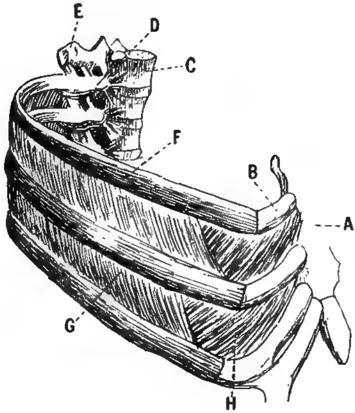


FIG. 89. Figure showing three ribs, their attachment to spine and sternum, and the muscles completing the thoracic wall. A. Sternum. B. Rib cartilage. C. Vertebral column. D, E. Attachment of ribs to spine. F. Rib. G, H. Outer and inner intercostal muscles.

The ribs run obliquely round the thorax, and are so jointed to the spine behind, and bound to the sternum in front, that when they are raised the sternum is thrown forward, and the cavity of the thorax enlarged. The upward movement of the thoracic cage is permitted by the elastic nature of the intercostal cartilages. Each pair of ribs forms one ring of the thoracic cage, and each ring slopes downwards. By pulling up the rings into the horizontal

position, the thorax must clearly be made larger, and the sternum thrust forward. At each inspiration the first rib is fixed, the second is drawn up towards the first by the contraction of the intercostal muscles, and the third towards the second, and so on for each succeeding rib. So soon as the contraction ceases, the thoracic cage sinks down into its former position, owing to its weight and the elastic recoil of the costal cartilages and of the lungs themselves. When the thoracic cavity becomes enlarged the lungs expand, and the reason for this can be easily seen by the following experiment:—

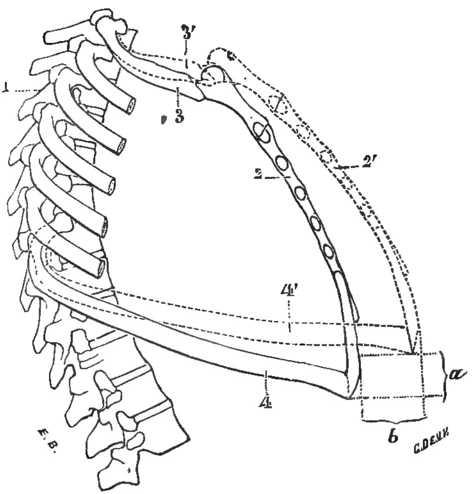


FIG. 90. Diagram to show how, as the ribs move upwards, the sternum goes forwards, and so increases the size of the thorax during inspiration. 1. Spinal column. 2. Sternum. 3. First rib. 4. Seventh rib. 2′, 3′, 4′. Position in inspiration *a*, *b* indicate the extent of movement.

Obtain a lamp-chimney and fit a cork to the narrow end; bore a hole through the cork and pass a piece of glass tube through the hole; tie a penny air-balloon on to the tube, and fit the cork tightly into the lamp-chimney, so that the balloon hangs within. Cover the other and broader end of the chimney with a loose sheet of wash-leather, fastening it securely with string (an air-balloon cut open will serve equally well for this purpose). Now, in this model, the glass chimney is the

thorax, the glass tube the trachea, and the air-balloon lying within the chimney the lung, while the sheet below is the diaphragm.

On pulling down and pushing up the diaphragm the air-balloon will alternately expand and collapse. Each time the diaphragm descends, the pressure of the air within the chimney (thoracic cavity) becomes less than that of the atmosphere. This must be so, because the same number of molecules of gas have to fill a larger cavity. On the other hand, the pressure of the air within the air-balloon is the same as that of the atmosphere, for the trachea is an open tube. By the difference of pressure the elastic air-balloon is distended. When the diaphragm ascends, the pressure within and without again becomes equalised, and the air-balloon collapses, owing to the recoil of its elastic wall.

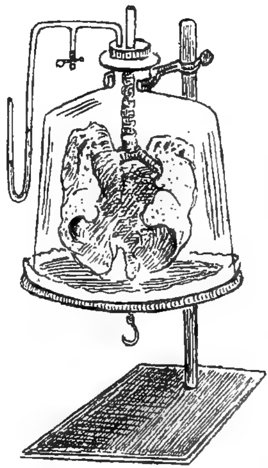


FIG. 91. Model for showing the action of the diaphragm.

In the case of the real lungs, the mechanism is the same.

When the diaphragm descends and the ribs ascend, air rushes down the trachea and distends each lung, so as to fill up the enlarged thoracic cavity. At the same time blood is sucked in greater quantity from the big veins into the right side of the heart, and thence more blood passes into the lungs. During expiration the lungs shrink, owing to the recoil of their elastic tissue. If the thorax be opened by a stab or gunshot wound, so that air can enter freely into one pleural cavity, the lung on that side will, owing to its elasticity, collapse, and air will be sucked at each breath, not into the lung, but in and out of the pleural cavity.

Carefully remove the intercostal muscles between one rib in a dead rabbit. The lung can be seen in contact with the pleura, open the pleura and the lung collapses. If both cavities be thus opened, respiration becomes impossible.

Any piece of lung contains air, and therefore floats in water. It is impossible to squeeze all the air out of the lung, for the walls of the little bronchial tubes are compressed at the same time as the air-sacs, and thus the air cannot escape.

The tidal air and vital capacity. At each ordinary breath a little less than a pint-pot full of air (20 to 30 cubic inches) is taken in and given out. This is called the tidal air. By the deepest inspiration an extra 100 cubic inches can be taken in (complemental air). Similarly, by the deepest expiration an extra 100 cubic inches can be breathed out (supplemental air). After the deepest possible inspiration has been taken, about six or seven pints of air (230 cubic inches—tidal 30, complemental 100, supplemental 100) can be breathed out by the deepest possible expiration. This quantity is called the *vital capacity* of a man.

Take a glass jar that will hold over a gallon, fill it with water and invert it in a bath of water. Pass a piece of rubber gas-tubing under the edge of the jar. Now take the deepest possible inspiration, and then blow through the tube into the jar for as long a period and as forcibly as you can. Water will be driven out of the jar to make room for the air. Hold the jar so that the water inside and outside is at the same level, and with a piece of gummed paper mark the level of the water left in the jar. Then take out the jar and pour water into it up to the mark. Measure the amount of this and it will give you your vital capacity.

Measure the greatest girth of your chest both in the position of full expiration and of deepest inspiration. The difference should measure in an adult some three inches, and can be made greater by a course of gymnastic exercises.

During natural quiet respiration there are within the lungs about five pints of air, and at each inspiration a little less than one pint of fresh air is taken into the trachea and larger bronchial tubes. This mingles by diffusion with the five pints of impure air lying in the smaller tubes and air-sacs, and a little less than one pint of the mixture is breathed out at the following expiration. Thus only a small proportion of the air within the lungs is changed at each respiration.

Inspired and expired air. The differences between expired and inspired air can be determined quite simply by analysis.

Obtain some lime-water from a chemist, place it at the bottom of a bottle, and shake it up with the air above. The lime-water remains clear. Now put a glass tube into the lime-water and blow through it : expired air will rapidly turn lime-water milky, owing to the presence of carbonic acid, for this produces a precipitate of calcium carbonate. Next pass two tubes through a cork, fix the cork tightly into a dry bottle. To one tube attach a football bladder partly distended with air. Breathe in and out of the bottle several times in succession, until you begin to feel suffocated. The bottle will become moist and warm. Expired air is saturated with the moisture taken up from the wet mucous membrane of the air-passages. On a cold day your breath passes off as a cloud of steam. Expired air is also warmed up to the temperature of the body, and thus heat is constantly lost by each respiration, both in warming the air and by the evaporation of water.

If, holding the bottle upside down, you take the cork out and pass a lighted taper within, the light will be at once quenched, for the oxygen will have almost entirely disappeared, and is replaced by carbon dioxide.

To analyse the air exactly, the apparatus represented in Fig. 92 is employed. The graduated tube is filled with mercury, and by opening the tap at the top and lowering the mercury reservoir a measured quantity

of air can be drawn within. On raising the reservoir B this air is driven over by a connecting tube into a bulb containing potash which absorbs the carbon dioxide; it is then sucked back again into the graduated tube and measured. The difference in the two measurements gives us the amount of carbon dioxide. The operation is repeated, with the difference that this time a bulb containing pyrogallate of sodium is employed. This absorbs the oxygen. The gas is once more drawn into the graduated tube and measured. The amount of oxygen is obtained from the difference between this measurement and the last. What is left unabsorbed is the nitrogen, with a very small amount of other newly discovered gases which exist in the atmosphere.

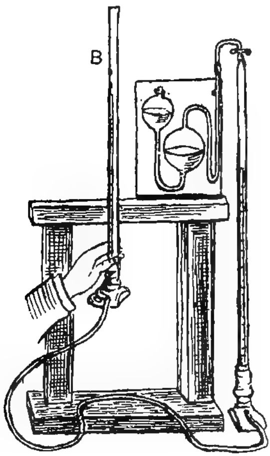


FIG. 92. Apparatus for analysing a sample of air.

With the above apparatus it can be determined that every hundred pints of atmospheric or inspired air roughly contain—

Oxygen . .	21 pints.
Nitrogen .	79 pints.
Carbon dioxide .	a trace.

This air after expiration, on the other hand, would contain—

Oxygen . . .	16 pints.
Nitrogen . .	79 pints.
Carbon dioxide .	4 pints.

The nitrogen remains the same: this gas simply dilutes

the oxygen, and is otherwise of no importance in respiration.

It will be noticed that not quite so much carbon dioxide is given out as oxygen is taken in. This is owing to the fact that while the greater part of the oxygen unites with carbon to form carbon dioxide, some of it combines with hydrogen in the tissues to form water. Such are the differences between inspired and expired air.

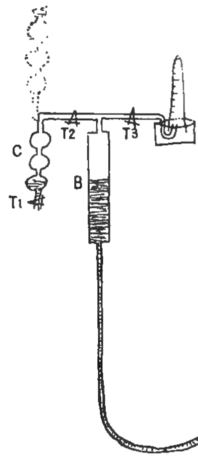


FIG. 93. Diagram of a pump for extracting the gases of the blood. A. Mercury reservoir connected by a flexible tube to the chamber B. C. Chamber for receiving the blood. D. Measure-tube for receiving the gases. T_1, T_2, T_3, taps.

The blood gases. If a sample of blood be collected from a large vein, and another sample from a large artery, the gases contained in each can be analysed by means of a gas-pump. The blood contains a great deal of gas, for from every hundred pints of blood there can be obtained about sixty pints of gas. The following is a rough outline of the method employed:—

Fig. 93 represents the gas-pump. The bulb C is placed in the position marked by dotted lines. The reservoir A, full of mercury, is raised until C is full of mercury. If the tap T_1 be closed and T_2 opened, on lowering the reservoir A more than thirty inches, the mercury will drop down out of the bulb C and leave a vacuum therein, for the weight of the atmosphere cannot support a column of mercury more than thirty inches high. A vacuum having been produced in C, this is lowered to the dependent position. The tap T_1 is next immersed in a measure-

glass full of defibrinated blood, and then opened for a moment. Some blood is thus sucked into the vacuum, and the quantity of blood withdrawn from the measure-glass is observed. The reservoir A is now lowered still further until there is a vacuum in the chamber B. The blood in C will at once begin to froth and bubble, and especially so if C be warmed. The loose chemical combination of oxygen with haemoglobin, and carbon dioxide with the salts of the plasma, is upset, and the molecules fly off into the vacuum. Warmth increases the movement of the molecules and makes them fly off more rapidly. The gases collected in the chamber A can be measured and analysed by a method similar to that employed for investigating the difference between inspired and expired air.

The difference between venous and arterial blood is found to be as follows :—

	100 *pints of venous blood yields about*	100 *pints of arterial blood yields about*
Carbon dioxide	46 pints	40 pints.
Oxygen	12 pints	20 pints.
Nitrogen	1 pint	1 pint.

Comparing the differences, you see that in venous blood loss of oxygen is greater than gain of carbon dioxide. This is again owing to the fact that some of the oxygen unites in the tissues with hydrogen to form water.

There is just as much nitrogen absorbed in blood as there is in water; this small amount does not vary, and is, as far as we know, of no importance. On the average, then, every 100 pints of blood passing through the lungs lose 6 pints of carbon dioxide gas and gain 8 pints of oxygen. Conversely, every 100 pints of blood passing through the tissues lose 8 pints of oxygen and gain 6 pints of carbon dioxide. From every 100 pints of air breathed, a man takes in 5 pints of oxygen, and at the same time loses

[1] All gas measurements are calculated at 0° C. and 760 mm. Hg. barometric pressure.

4 pints of carbon dioxide. Now, if a man respire, say, $\frac{2}{3}$ pint of air at a time, and eighteen times a minute, he will breathe 12 pints of air per minute, and in the course of one day $12 \times 60 \times 24 = 17{,}280$ pints of air. Taking the total amount as 17,000 pints, he will receive $170 \times 5 = 850$ pints, or about 100 gallons of oxygen, and give out $170 \times 4 = 680$ pints, or about 80 gallons of carbon dioxide. An ordinary pail holds about 2 gallons. It has been estimated that the amount of carbon given out by a man in the course of one day, if split off and separated from the oxygen, would be represented by $\frac{1}{2}$ lb. of charcoal. At the same time, a man loses by evaporation from the air-passages about $\frac{1}{2}$ pint of water per day.

The exchange of gases between the blood and air. Gases easily mix with each other, for the molecules are in rapid motion, and quickly diffuse through any space. If a porous pot full of carbon dioxide be placed in a bottle of oxygen, the two gases pass through the pores until equally mixed. On opening a bottle of soda-water, the carbon dioxide which was forced into solution by the manufacturer comes bubbling off, and mixes with the air.

In the matter of diffusion each gas behaves independently of the others: any one gas in a mixture will always diffuse in the direction where the pressure of that particular gas is least.

Open the body of a dead toad and observe the pink lungs. These are large pink bags containing air; in the frog they are much smaller. Tie a thread round the top of one lung after squeezing most of the air out. Cut through the lung above the thread, and tie a weight on to the thread, then drop the lung into a glass of soda-water. The lung will quickly become distended with carbon dioxide gas, which passes by osmosis out of the soda-water into the lung. Tie up the other lung and drop it into a solution of hydrogen peroxide (H_2O_2)—this can be obtained from the chemist. The contact of the living tissue

decomposes the solution, and the lung will quickly become distended with oxygen.

Examine under the microscope a toad's lung placed in a watch-glass full of soda-water. As it becomes distended you will see very clearly the network of capillaries on its wall. These are set very close together and are full of blood corpuscles. Leave a toad's lung (distended with air) until it is dry. Then cut it open and observe both the cellular structure and the pulmonary vessels. The artery, containing venous blood, runs on the outside, and gives off the network of capillaries which join the vein. The latter runs up the inside of the lung and contains arterialised blood.

If a bottle of sugar and water be corked up after the addition of a little yeast, fermentation will take place owing to the growth of the yeast-cells. Alcohol and carbon dioxide are produced thereby, and the latter collects in such quantity that the cork may be driven out of the bottle.

Similarly in the tissues of the body, carbon dioxide is produced out of sugar by the fermentation processes that go on in the cells and permeates through the wall of the capillaries into the blood stream, where it forms a loose chemical combination with the proteids and sodium salts of the plasma. In the tissues, carbon dioxide is set free; in the plasma, there are the substances greedy to combine with it. The gas is thus carried away from the tissues and brought by the blood to the lungs. Here, through the wall of the pulmonary capillaries, some of the carbon dioxide permeates, for the pressure of this gas is greater in the blood than it is in the air-sacs. The carbon dioxide in the air-sacs in its turn diffuses into the air within the air-passages, and some of this is expelled at each act of respiration. Similarly in the case of oxygen, the protoplasm of the tissues is most greedy to combine with this gas. In the tissues there is no free oxygen, it is all chemically combined; thus the oxyhaemoglobin in the warm blood parts with its oxygen to the tissues, just as it does in a vacuum-pump. In the pulmonary capillaries the reduced haemoglobin again meets

with oxygen which diffuses from the air-passages into the air-sacs, and thence passes by osmosis through the wall of the air-cells into the blood. The reduced haemoglobin combines with the oxygen as fast as the gas enters the blood, and once more becomes oxyhaemoglobin.

The following represents at a glance the course of the gases. They move from the place where they are more to the place whey they are less *concentrated*:—

Oxygen. Atmosphere > air-passages > air-sacs > arterial blood > tissues.

Carbon dioxide. Tissues > venous blood > air-sacs > air-passages > atmosphere.

Tissue respiration. The exchange of gases between the blood and the tissues is often called *Tissue Respiration.* The protoplasm of the tissue-cells combining with the oxygen stores it up so that the cells continue to live for a short time after the supply is cut off. The leg of a frog (freshly killed) can be hung up in a jar full of hydrogen or in a vacuum-chamber, and made to contract in the absence of oxygen. There is stored in the muscle a contractile material consisting of a chemical combination of muscle-plasm with oxygen. The frog's muscles will contract until this substance is exhausted. In order that the muscle may recuperate, fresh oxygenated blood must be supplied. If the vein coming from the jaw-muscles of a horse be opened, and some of the blood withdrawn and analysed, firstly when the animal is at rest, and secondly when chewing food, it will be found that there is more carbon dioxide and less oxygen in the second sample than in the first. The muscles when at work use up more oxygen and produce more carbon dioxide. The amount of carbon dioxide breathed out by man during muscular exertion may be five times as great as during an equal period of rest. During hard exercise the amount of carbon dioxide expired may often exceed that of the oxygen taken in. The contractile substance in such case is broken down faster than it is built up. During the resting-time that follows, an excess

of oxygen is taken in and the contractile substance restored. In order to keep up the body heat, more oxygen is taken in and carbon dioxide excreted in cold weather than in hot. A man who is cold moves actively about and contracts his muscles. In hot weather he is inclined to be indolent. If the glow organ in the tail of a glow-worm be placed under the microscope, the cells may be seen to glow so long as air is supplied; on withdrawing oxygen the light becomes gradually extinguished. In the absence of oxygen ciliated cells gradually cease to work; they are restored by fresh air. The tissues of the lung and the corpuscles in the blood, like all other living tissues, use up oxygen and produce carbon dioxide, but the chief seat of combustion is neither in the blood nor the lungs, but in the tissues, and above all in the muscles.

Asphyxia. The prolonged absence of oxygen produces death. The onset of death is slow in cold, but quick in hot-blooded animals. If a man be choked by the closure of his windpipe, he struggles violently for breath; all the muscles which pull on the thorax or compress the abdomen come into action in order to force open the air-passages. Thus his whole body is thrown into convulsions. Owing to the violent compression of the thorax, the blood cannot easily get into the heart; thus the veins become engorged, and as the blood becomes more and more venous, the man gets blacker and blacker in the face. It is owing to excess of carbon dioxide rather than to the want of oxygen that the nerve-cells in the brain discharge tumultuous impulses which convulse the muscles. Not only the skeletal muscles are contracted, but also the muscles of the arteries, intestines, and bladder. Finally paralysis of the brain follows and the man lies quiet, save for an occasional, convulsive spasm. His heart is still beating, but soon flickers out, and then the man is dead. So long as the heart continues to beat the man can be recovered. The windpipe must be freed from obstruction and the chest rhythmically and for-

cibly squeezed between the hands so to imitate respiration. In drowning, water is inspired into the lungs; the man should be placed face downwards with his tongue drawn out and a coat rolled up and put under his chest. On squeezing the thorax in this position the water will be expelled and air drawn into the lungs. The rhythmic compression of the thorax not only draws air in and out of the lungs, but squeezes the blood through the heart and thus helps to restore the circulation. It may take half an hour's artificial respiration to produce signs of returning life.

Dyspnoea. This name is applied to the forcible strained breathing which occurs when a man is 'winded' in a race, and is seen in patients suffering from lung or heart disease. Sitting upright and grasping the chair or bed with their hands, the patients, to expand the chest, employ all those muscles which pass between the upper limb and the thoracic wall. By forced breathing not only more oxygen is obtained, but the circulation of the blood through the diseased heart or lungs is aided; it is the excess of carbon dioxide in the blood flowing through the brain that evokes dyspnoea.

Breathe in and out of a football bladder or air pillow and note how your breath gets deeper and deeper as the percentage of carbon dioxide increases. No such result follows if you put potash solution in the bag to absorb the carbon dioxide.

The nervous control of respiration. Situated in the medulla oblongata, near to the vaso-motor and cardio-inhibitory centres, lies the respiratory centre. If this part of the brain be destroyed the animal ceases to breathe, and thus a man dies at once when his neck is broken. From the centre impulses are discharged rhythmically to the nerves which pass to the diaphragm and intercostal muscles. Two *phrenic* nerves issue one from either side of the spinal cord in the neck, and passing down the thorax supply the diaphragm. If these nerves be cut the diaphragm ceases to move, but the chest continues to rise and fall, and

sufficient air is thus obtained. A man breathes more with his diaphragm; a woman, owing to corsets and tight lacing, uses her thoracic muscles rather than her diaphragm. The respiratory centre is easily influenced by sensory nerves. Thus irritation in the nose causes a sneeze; in the larynx or windpipe, a cough. A dash of cold water on the skin produces a deep inspiration. Sharp pain or fear makes a man hold his breath. Respiration stops, too, for a brief space of time whenever a man swallows. In coughing the glottis is closed and then burst open by a forced expiration. The blast of air expels any foreign substance which is irritating the laryngeal nerves. In sneezing, the mouth is shut off from the pharynx both by the descent of the soft palate and approximation of the pillars of the fauces, and the air is then suddenly driven out through the nose. The object of sneezing is to cleanse the nose. Sighing is a deep inspiration, the chief effect of which is to draw from the veins into the right heart an extra quantity of blood. Thereby the circulation in the brain is improved. Yawning, by the general stretching and contraction of the muscles, presses the blood from the veins on into the heart and improves the circulation. Crying, shouting, and laughing, all powerfully influence the circulation of the blood, and thus are good exercises and by no means to be always discountenanced and suppressed in children. There is no more natural and healthy relief to the distressed brain than a good cry. The respiratory centre is controlled by the quality and quantity of the blood which circulates through it, and particularly by the amount of carbon dioxide in the blood. The slightest variation in the percentage of carbon dioxide in the air-sacs of the lungs affects the depth of breathing. The breathing is adjusted to keep this percentage constantly at 5–6 per cent.

The natural rhythm of respiration seems, however, to be maintained partly by the action of the vagus nerves. Up these important nerves there run afferent fibres which

convey messages from the lungs to the respiratory centre. At each inspiration these fibres are excited by the expansion of the lungs, and the impulses passing to the respiratory centre evoke an expiration. At each expiration the same nerves are excited by the collapse of the lungs, and in this case the impulses call forth an inspiration. So every inspiration provokes an expiration, and every expiration calls forth an inspiration.

We can, if we try, either stop the respiration or breathe very rapidly for a short time, but in either case the power of our will is soon exhausted.

Try to breathe fifty times a minute ; you will soon find that you cannot keep up this rate.

We live as a rule quite unconscious of the natural rhythm of respiration.

Power of suction. A baby can suck by closing its lips tightly round the nipple and depressing the floor of the mouth so as to make a vacuum within. The milk is forced up by atmospheric pressure to fill the vacuum. By the greatest effort we can suck water up a tube about five feet long. Similarly we can force a column of water up a tube about five feet high, that is to say by blowing out with our greatest force. This pressure is about equal to the pressure of blood in the arteries.

Poisonous gases. Effect of altering atmospheric pressure. Carbon dioxide is a poisonous gas. If a man be enclosed in a small air-tight chamber he will, as the carbon dioxide begins to increase in amount, breathe more and more heavily. 10–15 per cent. of carbon dioxide renders a man unconscious. If the carbon dioxide is removed by potash the man in the chamber can continue to live until the oxygen falls to about 7 per cent., in place of the 21 per cent. found in the atmosphere. This is possible owing to the greed with which haemoglobin combines with oxygen. Similarly a man can ascend a mountain or rise in a balloon until the pressure of the atmosphere has fallen to one-third

of what it is at sea-level. The weight of oxygen in 100 pints of air is then only one-third of what it is at sea-level. Mountain sickness is due to this want of oxygen. At a height of 12,000 to 15,000 feet most people find it difficult to climb. Effort to do so increases the distress, for more oxygen is then required. Training makes a great difference in this respect, and it is therefore dangerous for persons out of training to scale the great heights of the Alps. They become exhausted both by the hard work of climbing (lifting their own weight up say 10,000 feet), and by the want of oxygen. Mountaineers overcome the deficiency of oxygen by greater development of the organs of respiration and circulation. They, too, have more haemoglobin in their blood. The blood is carried round faster and the lungs are better ventilated in them.

Carbon monoxide is a gas found in coal-gas and in coal mines, and is given off from fires. This gas, if it gain entry into the lungs, combines with haemoglobin, and by displacing oxygen produces asphyxia. People are thus killed by after-damp in colliery explosions, by leaving gas-taps open, or by having charcoal stoves burning with insufficient ventilation in their bedrooms.

Men can continue to live and work in a chamber, such as a diving-bell, into which air is forced by a pump under considerable pressure. If the pressure be increased above three or four times that of the atmosphere dangerous symptoms of paralysis, &c., may arise when the men leave the diving-bell. The symptoms are due to bubbles of nitrogen escaping from the blood and damaging the nervous and other tissues, just as the bubbles appear in a soda-water bottle when it is uncorked.

The body fluids dissolve 1 vol. per cent. of nitrogen at 1 atm., 2 vol. at 2 atm., 3 vol. at 3 atm., and so on. If they come out quickly from the compressed-air chamber the excess of dissolved gas is set free as bubbles. All such accidents can be prevented by making the workman come out very slowly, so that there is time for the excess of dissolved gas to escape from the lungs.

In the case of a diver, air is forced through a tube into his diving-bell or dress. As he sinks deeper and deeper and the pressure of the water increases, the greater must be the pressure of the air forced into his diving-dress. The diver, too, must come up slowly to prevent gas bubbles forming in his blood. Even then he cannot go safely beyond a depth of 200 feet (7 atmospheres of pressure; 33 feet of water = 1 atm.), because the excess of oxygen at such high pressures poisons the nervous system and produces inflammation of the lungs.

Ventilation. It is generally supposed that beside carbon dioxide other poisonous substances are excreted in the breath. This opinion, however, has not stood the test of experiment.

The stuffiness and ill smell of a crowded room of entertainment is due to exhalations from the clothes, skin, gas-burners, &c., and fatigue results from the effect of the heat and excitement. Free ventilation is necessary to keep a room sweet and healthy. It is most important to remember that light and air are the best germicides. Sunlight kills bacteria and many are destroyed by oxygen. Sunlight should never be excluded from our rooms for the sake of carpets and furniture. It is far better that they, rather than our complexions, should fade. When in over-crowded and dirty rooms the air is vitiated, bacteria and parasites flourish. The air in an ordinary sized bedroom should be changed completely once an hour for each person occupying it; thus windows and fire-places must never be completely closed up. There should be allowed a cubic space measuring 10 feet each way for each person occupying a bedroom or working in a factory. Plenty of fresh air and light, exercise, hard work, and a spare diet are the simple rules for a healthy life. The more a man tries to protect himself from illness by over-clothing, shutting windows, and staying indoors for fear of colds, by over-eating to keep up his strength, by idling for fear of over-working, the less likely is he to keep himself in vigour and health.

CHAPTER XXIV

FOOD AND ITS DIGESTION.

Loss and gain. Suppose by means of a delicate balance a man be weighed at stated intervals of time during the course of a day. At the end of a few minutes after the first weighing he will be found to have lost weight. This loss will continue until after the taking of a meal, when his weight will be suddenly increased in exact proportion to the amount of food and drink taken. Immediately after the meal, loss of weight will begin again and continue until the next meal comes to counteract this loss. At the end of the twenty-four hours the man will be found to weigh much the same as he did at the beginning, for an almost exact balance is struck between gain and loss. If the same experiment were performed on a new-born baby, the child should be found to have gained in weight, for in it the intake is greater than the loss. Thus the child grows in bulk and stature. If at the beginning and end of the twenty-four hours the weight were taken of a man starving, or one in a fever, or of a bicyclist trying to cover the greatest possible distance in this time, in all these the loss would be found to be greater than the gain. If a man's excretions were separately collected during the twenty-four hours and weighed, the loss would be found to be *about* as follows :—

From the bowel .	5 ozs. excrement
,, ,, skin	25 ozs. sweat
,, ,, kidneys	55 ozs. urine
,, ,, lungs . .	35 ozs. { carbon dioxide gas and water vapour.
Total	120 ozs.

The total loss is then about eight pounds, and of this water forms the greater part (about six pounds); the remainder (about two pounds) consists of those other waste materials which result from the breaking down of protoplasm into simpler chemical substances, whereby the energy of life is produced. In considering these waste materials we can for the moment set aside the excrements or *faeces*, for these consist mostly of the undigested food and water which have never entered into the substance of the body, but have simply passed through the alimentary canal. Leaving these aside we have excreted—

	As water.	*As solids in solution.*	*As gas.*
From the lungs .	10 ozs.		25 ozs. carbon dioxide.
,, ,, skin .	25 ozs.	$\frac{1}{4}$ oz. salts and traces of organic material.	a little carbon dioxide in solution.
,, ,, kidneys	53 ozs.	$1\frac{1}{4}$ oz. urea. 1 oz. salts.	,,
	Total about 88 ozs.	Total about 27 ozs.	

In carrying out the above experiment the method employed would be something as follows:—

Sulphuric acid is a substance which greedily absorbs water. Soda-lime is a substance which absorbs with equal greed carbon dioxide.

Suppose a man to be placed in the chamber D as represented in Fig. 94, and a current of air be drawn through the chamber in the direction of the arrows. The air will pass through the bottles A, sulphuric acid, B, soda-lime, and C, sulphuric acid, into the chamber. It will arrive there freed from carbon dioxide and water. After leaving the chamber, the air charged with carbon dioxide and water given off from the man will pass through the

sulphuric acid bottle E, the soda-lime bottle F, and the sulphuric acid bottle G. If the sulphuric acid bottle E be weighed at the beginning and end of the day, the increase in weight will tell us how much water the man has given off from the skin and lungs. If the bottles F and G be also weighed together, the increase here will tell us the amount of carbon dioxide given off[1]. During the course of the day the man will collect his urine in a bottle, and this can be weighed. The water, urea, and salts can

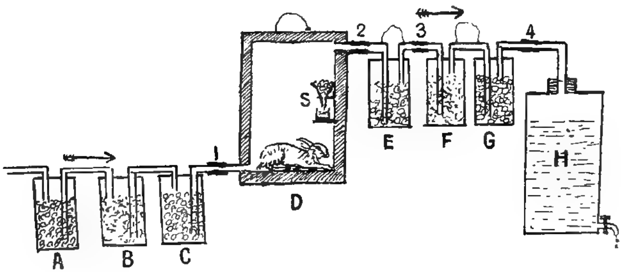


FIG. 94. Diagram of apparatus for estimating the heat given off and respiratory exchange. D. Chamber containing animal. S. Funnel full of broken ice; the water from the melted ice is collected in a pot. D can be disconnected at 1 and 2, and weighed to obtain animal's loss in weight; E, disconnected at 2 and 3, and weighed = water vapour given off by animal; F and G, disconnected at 3 and 4, and weighed = carbon dioxide given off by animal. From the ice melted in S the amount of heat given off is reckoned. H. Vessel from which water is escaping and thus aspirating air through the apparatus.

be separated by special methods and weighed. By means of such a chamber the loss suffered by a man while in conditions of rest, sleep, manual or mental work, can be respectively estimated and compared.

Urea is a substance of great importance, as it is the nitrogenous waste product of the body. Almost half the weight of the urea is, on analysis, found to be nitrogen. Carbon, hydrogen, and oxygen also enter into the constitution of its molecule. If the body of an animal be burnt, ammonia, carbon dioxide, and water pass off, and mineral salts are left as ash. In the living body, as the result of

[1] The bottle F is necessary to catch the water which soda-lime gives off when it combines with carbon dioxide.

a much slower process of combustion, urea, carbon dioxide, water, and mineral salts are continually lost. Urea is not quite so simple a substance as ammonia, but it is easily converted into the latter by the ferment action of bacteria. Urea can be synthesised by the chemist, who, in the laboratory, can take the elements carbon, hydrogen, oxygen, and nitrogen, and by certain processes build them up into urea. The chief waste products of the body are therefore water, a compound of oxygen and hydrogen, carbon dioxide compounded of carbon and oxygen, urea compounded of carbon, hydrogen, oxygen, and nitrogen, and mineral salts. The saline matters consist chiefly of common salt or chloride of sodium. There are in the urine, chlorides, phosphates and sulphates of potassium, sodium, calcium, and magnesia. To make up this loss food must be taken in equivalent amount. Now an animal cannot, except in the case of oxygen, take inorganic substances as food and build these up into protoplasm. On the other hand, plants can do so, and it is either from plants, or from animals which have fed on plants, that man takes the complex food materials which he requires, namely, proteids (meat), fats, and carbohydrates (starch or sugar). In addition, man obtains mineral salts which are present in plants; he drinks water and breathes in oxygen. You will remember that plants, during the process of growth, store up the sun's energy. It is this energy that is once more set free in man.

Food. The food of man consists of proteid, fat, carbohydrate, water, salts.

The chief proteids we eat are the vegetable proteids found in flour, oatmeal, peas, beans, and potatoes.

Albumin and globulin, found in white of egg and blood.

Myosin, found in lean meat.

Casein, found in milk and cheese.

Gelatin, obtained from bones and ligaments by boiling.

Obtain from the druggist an ounce or two of each of the following:—1. Strong nitric acid. 2. Ammonia. 3. Caustic potash (20 p.c. solution). 4. Iodine solution. 5. Copper sulphate (1 p.c. solution).

The general test for proteids is this. Add to them some nitric acid and boil; they then become yellow in colour, and on adding ammonia, the colour deepens to orange. Take some flour and knead it in a muslin bag under a water-tap. A sticky substance will be formed which is called *gluten*; this is the flour proteid changed by the action of water. Owing to the sticky gluten which it contains, flour can be kneaded into dough and moulded into various forms for cooking. Place some of the gluten in a test-tube with a little nitric acid and boil it:—a yellow colour will be obtained. Repeat the test with oatmeal and pea-flour. These flours also contain starch. This, like sugar, is a carbohydrate, consisting of the elements carbon, hydrogen, and oxygen. Collect the water with which you washed the flour in the muslin bag. This is whitened by starch powder. On boiling, the starch dissolves, and the solution becomes translucent. If a drop of iodine be added to cold starch solution in a test-tube an intense blue colour will result. The colour disappears on heating the solution, but reappears on cooling it again. The test-tube can be cooled by placing it under a stream of cold water.

Test some bread in a similar way, and you will obtain evidence of proteid and starch. In the process of baking, however, some of the starch has been changed into other forms of carbohydrate, namely, dextrine, which is like gum, and grape-sugar. Test for the presence of sugar thus. Make an extract of some bread in a test-tube and add a few drops of a solution of copper sulphate and some strong solution of potash. On boiling, a reddish yellow precipitate will appear if sugar be present. There is very little fat present in flour or bread, and thus we eat butter with bread, and to puddings made of flour we add suet.

Now obtain some milk. Examine a drop under the microscope, you will see that it swarms with minute round bodies. These are droplets of fat, and, being lighter than water, they rise to the top as cream when milk is allowed to stand.

By churning the fat, droplets can be worked together till they form lumps of butter.

The white colour of milk is due to the fat contained in it. A little oil shaken up with water will become white like milk. The oil is split up into tiny droplets and forms an *emulsion* of fat. The droplets, however, soon run together again. In the case of milk the droplets are kept from running together, for each little drop is coated with a film of the proteid caseinogen. By adding vinegar or acetic acid to milk the proteid caseinogen is curdled. The curd entangles the butter.

Milk is soured by the ferment action of bacteria. The sugar of milk is changed into lactic acid, and this precipitates the caseinogen. Cheese is formed from curdled milk.

A clear fluid, the *whey*, gradually separates from the curds. When this has taken place pour off some of the whey. Test the curds with nitric acid. On adding this and boiling, the yellow colour indicating proteid is obtained. To the whey add copper sulphate solution and potash. On boiling, a yellow-red precipitate indicating sugar is obtained. Thus we see milk contains proteid, fat, and carbohydrate, and these are held in a watery solution of mineral salts.

Test some egg-white for starch, for sugar, and for proteid. You will only obtain evidence of the last.

Proteid foods. In the following table is set off the approximate amount of each constituent found in 100 ounces of each of the most important foods:—

	Water.	*Proteid.*	*Carbohydrate.*	*Fat.*	*Salts.*
Bread .	34	8	55	1	2
Peas . . .	15	23	57	2	3
Oatmeal . .	12	11	68	6	3
Rice . . .	13	8	$77\frac{1}{2}$	1	$\frac{1}{2}$
Potatoes .	75	2	22	0·3	0·7
Meat . . .	75	19	1	4	1
White fish .	78	18	1	2	1
Egg . . .	74	14	—	$10\frac{1}{2}$	$1\frac{1}{2}$
Milk . . .	87	4	4	4	1
Cheese . .	37	33	—	$24\frac{1}{2}$	$5\frac{1}{2}$

Proportion of nitrogenous and carbonaceous foods required. In the $1\frac{1}{4}$ oz. of urea which is daily lost from a man's body, there is combined a little more than $\frac{1}{2}$ oz. of nitrogen, while in the carbonic dioxide lost there is combined about 8 ozs. of carbon. The nitrogen lost from the body is in proportion to carbon approximately as 1 is to 15. It is therefore obvious that the man's daily allowance of food should contain nitrogen and carbon in the same proportion. If one be taken in excess, part of the food will be wasted. The digestive organs, moreover, will be taxed with extra work which can prove of no value to the body. If, on the other hand, the amount of one absorbed be too little, the man must, to maintain his energy, consume part of his body substance, and in consequence will lose weight and eventually die of starvation. Now in pure albumin, such as the white of egg, the proportion of nitrogen to carbon is found to be as 15 to 53 or 1 to $3\frac{1}{2}$. Thus to secure the right amount of carbon from a diet of egg-white, a man would have to eat four times as much nitrogen as he requires. In the case of lean meat, he should eat 4 pounds a day to gain sufficient carbon, while $\frac{3}{4}$ pound would yield him a sufficiency of nitrogen. To continue to eat 4 pounds of lean meat a day would be an impossible task. The meat becoming nauseous to the palate would in the end produce diarrhoea. A dog can be brought to live on lean meat alone, but a man cannot. Since fat, starch, or sugar contain plenty of carbon but no nitrogen, it is obvious that by judiciously mixing these with our proteid food the required amount both of nitrogen and carbon can be obtained. In about 2 pounds of bread there is enough carbon for the day's needs, but this quantity yields only half the necessary amount of nitrogen. By combining $\frac{3}{4}$ pound of lean meat with 2 pounds of bread, a sufficiency of both elements is obtained without

unnecessary work or waste, and on such, with plenty of water and a little common salt, man can live.

The proteid and carbonaceous food, when weighed dry and free of water, should, to suit the adult, be in the proportion of 1 to 4. Milk contains almost equal quantities of proteid, fat, and sugar. Thus the proteid is in proportion of 1 to 2 parts of fat and sugar. The infant naturally lives on milk alone. Owing to the rapid growth of its tissues a higher proportion both of water and of proteid is required in its diet. None of the food stuffs has exactly the right proportion for the adult, no one forms a perfect food like milk does for the infant. The two that come nearest are milk and oatmeal, as you will see by the above table. Milk has an excess of nitrogenous, and oatmeal an excess of carbonaceous food. Therefore oatmeal eaten with milk is a perfect food, and one on which the people of Scotland have lived and thrived.

Similarly, by mixing potatoes or rice with milk the right proportion can be obtained. To live on boiled potatoes alone an Irishman must eat about 7 pounds a day, so great is the proportion of water, and so small the proportion of proteid. By adding milk or eggs to his diet he can half the necessary quantity of potatoes, and thus every Irish peasant keeps a cow and chickens. The following is a liberal diet for a hard-working man :—

Breakfast.	*Dinner.*	*Supper.*	
Oatmeal, 3 ozs.	Lean meat, 5 ozs.	Bread, 6 ozs.	or bread, 10 ozs., cheese, 3 ozs.
Milk, ¾ pint.	Fat, 1 oz.	Butter, ½ oz.	
Bread, 6 ozs.	Potatoes, 6 ozs.	Lean meat, 4 ozs.	
Butter, ½ oz.	Bread, 4 ozs.	Potatoes, 6 ozs.	
Jam, ½ oz.	Apples, 6 ozs.		

No other kind of food but proteid will yield nitrogen in a form such as the body can use. Therefore we must have proteid, and whether we combine with it fat or starch or both is of minor importance, so long as

sufficient carbonaceous food is obtained from one or the other. The famous explorer Nansen with his companion lived through the Arctic winter on bear's flesh and fat. On returning to civilisation they were fêted and banqueted on numberless kinds of flesh, fruit, and vegetables. Probably the latter régime was more difficult to endure than the former. The instinct of man is to take fat in the winter or in cold climates, and in the summer or in hot countries to choose carbohydrates. When an equal weight of fat and starch are burnt in a calorimeter, the former yields considerably more heat than the latter.

Fat. The three chief fats eaten by us are stearin, palmitin, and olein. The last is a fluid oil. Stearin is solid at ordinary temperatures. Animal fats are composed of a mixture of the three, and in such proportions as to be semi-fluid at body temperature. The fats, by the action of bacteria, become rancid, and are split up into glycerine and fatty acids. The latter are unpleasant to the taste; on adding an alkali, such as potash, to a fatty acid, soap is formed.

Try to dissolve olive oil in water. It mixes when shaken but soon separates, and comes to the top. Add a few drops of potash and shake again. The liquid becomes milky with fine droplets of fat—an emulsion—which may be seen under the microscope. The potash reacts with traces of fatty acid in the oil, and forms soap. The soap coats the fat drops and prevents them running together. Fat dissolves in ether, chloroform, and hot alcohol (beware of ether and alcohol near a flame). Warm a grease stain on paper, it does not disappear—fat is not volatile. Boil a little oil with potash for fifteen minutes. Soap and glycerine are formed. Add sulphuric acid and the fatty acids are set free from the soap. These are insoluble in water and rise to the top.

Carbohydrates. In the group of carbohydrates must be included sago, tapioca, and arrowroot, which are all composed of starch. While arrowroot is of a much higher price, it possesses no claim for preference over any other

and cheaper form of starch. Glycogen or animal starch occurs in the liver and muscles of animals. The sugars likewise fall into this group; cane-sugar, grape-sugar, malt-sugar, milk-sugar are varying forms. Treacle and honey, jams and sweets are sugar foods. *Cellulose* is a very insoluble form of carbohydrate. Of it the bark and fibres of vegetables and seeds are composed. This substance acts as a natural purgative. It is indigestible, but adds to the bulk of the food and promotes the action of the bowels. Thus figs, prunes, apples, and jams are useful in many cases for relieving constipation. A rabbit dies of constipation if cellulose be withheld from its diet. Young children and adults with delicate stomachs are liable to be irritated by cellulose, and the amount of this in their diet must then be restricted.

Starch occurs in the cells of plants as granules with a cellulose coat. The granules vary in shape so that it can be told by the microscopical appearance from what plant the starch came. Starch does not dissolve in cold water. Boil it and it dissolves. The heat ruptures the cellulose envelope and sets the starch free. Add iodine to starch solution. An intense blue results which disappears on heating and reappears on cooling. Starch solution cannot diffuse through an animal membrane. Boil some starch solution gently with dilute sulphuric acid for some minutes. The solution will no longer give blue with iodine, but a red precipitate with copper sulphate and caustic potash, for grape-sugar is formed thus from starch. The saliva has a like effect.

Many of the foods, such as flour, oatmeal, rice, potatoes, contain both proteid and carbohydrate; the latter is generally in the excess, but whenever any proteid be present in any article of diet it is classed among the proteid foods. Peas and lentils are very rich in proteid, but in a form not so digestible as is animal proteid. When cooked these foods are far more bulky than meat.

Mineral salts. Mineral salts are present both in

vegetable foods and in meat. In the former, salts of potassium are in excess, and therefore probably we eat common salt (sodium chloride) to balance the excess, for potassium tends to displace the sodium salts from the blood. Animal eaters like the Esquimaux never touch salt, while to a vegetable eater, such as an Italian labourer, it is a necessity. This being the case it is of the utmost folly to tax salt. Such a tax impoverishes the country by lessening the health of the workers.

Condiments and stimulants. Certain substances are used by man for the purpose of pleasing the palate, exciting the nerves of taste, and so producing an increased flow of digestive juices and better digestion. These substances, such as pepper, mustard, &c., are called condiments. Other substances, such as tea, coffee, alcohol, coca, kola, are used as stimulants. There is no stimulant known which does not produce reaction afterwards; and thus while such substances may be used with safety in great moderation, they should not be employed as a 'pick-me-up' to relieve a feeling of weariness or misery. Such use sets up a habit, and the constant stimulation of the nervous system, at a time when it should rest, takes the sufferer ever deeper into the mire.

If alcohol be taken it should be no more than a glass of wine or beer at meal-times; spirits should be regarded as a drug to be used under doctors' orders. To take alcohol between meals and as a relief to feelings of fatigue is most dangerous. Unwittingly and insensibly the strongest of us might thus be led into a path of ruin. The degenerations of the tissues of the body and the terrible loss of nerve power produced by dram-drinking, cannot be too forcibly impressed upon us all. If once the habit of alcoholism be firmly established permanent cure is almost impossible,

and can be effected only, if at all, by the strictest enforcement of restraint over a long period of time.

Patent medicines and foods. In these days of advertisements it is as well to warn the reader against the lies of the trader and the quack. The method of fortune-making by advertisement is to sell a well-known and cheap article at a dear price, under a new name with a new flavour added for disguise. The sale is effected by puffs in the newspapers; these are composed of a tissue of lies and false testimonials, some of which are written by credulous fools, but most by men who are paid to write the same. By insisting on the truth of a false statement, and repeating it often enough, the liar will even come to believe his own lie. Knowing this failing of the human race, the quack-medicine vendor and patent-food seller successfully trade on the credulity and folly of the public. The public believes the assertion of the quack that he possesses some secret drug of wonderful power, capable of healing half the diseases man is heir to. Let the reader consider that there are thousands upon thousands of the acutest intellects of the age engaged on scientific work, and that the real discovery of such a prepotent drug would bring to any one of these honour and position among the greatest men of the time. Is the quack-medicine vendor accepted and honoured among such? On the contrary, his vaunted pills when submitted to analysis in chemical laboratories are found to consist of aloes, Epsom salts, or other common drugs which the quack buys for a few pence a pound, and sells for a shilling an ounce, advertising them as worth a guinea a box. Most of the minor ailments are produced by errors in diet and lack of healthy exercise. These ailments are relieved by a purge, and the public are persuaded thus to buy fruit-salt or pills for a shilling when the required article, aloes or Epsom salts, can be obtained for a penny. Among the

numberless quack medicines sold for nervous exhaustion, many are altogether valueless, and some contain stimulants such as alcohol or coca, and are highly dangerous. The electric belts, so much vaunted, give off little electricity, and this little is valueless as a remedy. Nervous exhaustion can be cured not by drugs or electricity but by changing the habits of life. Congenial employment and exercise in the open air and sunlight are worth infinitely more than all the drugs and electrical treatment in the world. Errors in living can be atoned for not by the taking of medicines, but by learning the art of living, and of this lesson spare diet, hard work, and exercise form the first and last page.

Not only does health depend upon following the laws of nature but also a virtuous life. The peevishness and sleeplessness of young children, the bad temper and spoilt behaviour of older children, arise almost entirely from wrong feeding, coupled often with insufficient exercise. The proper punishment for a naughty child is a plain diet of bread and milk and hard muscular exercise. The biliousness of their elders, ill-temper and impaired judgment, gout and other degenerative diseases are frequently to be attributed to over or wrong feeding and want of hard muscular work. Persuade a man in an ill-temper, morose and discontented, to bicycle twenty miles, and let him miss his tea and come in hungry and late for his supper. The cloud of bitterness will be swept from him, for his body will be cleared of surplus food and his brain cleansed by the increased vigour with which the blood has circulated through it.

In countries other than England the patent-medicine vendors are forced to publish the ingredients of their mixtures, and the Governments warn the public and state the nature and exact price of the ingredients. In England the people are allowed to be fooled and defrauded

of millions of money by quacks, while the Government, to its disgrace, does nothing to protect the poor, the weak, and the ignorant from them.

Patent foods. Meat juices and extracts. In the matter of patent foods words of warning are equally necessary. For example, in the case of beef juices and extracts, in none of these is a large quantity of food really concentrated into a small bulk as the public are led to believe. Suppose a man chose to obtain the necessary amount of proteid for one day from any one of the advertised meat-juices, he would have to eat about eight shillings' worth. An eightpenny mutton chop or beef-steak would give him a larger and far more wholesome meal. A glass of milk contains more nourishment, and that in a more digestible form, than any cup of meat extract that can be bought in the market, and it is to be obtained at a far lower price. The white of an egg broken into a cup of water and flavoured with a little beef-tea will give an invalid more and better proteid food than can be obtained from any purchasable juice or extract of meat. The only way to get the nourishment out of a chop or steak is to eat the whole of it. Now meat extracts and beef-tea contain but a fraction of the proteids with a large amount of nitrogenous waste products allied to urea. The latter throw extra work upon the kidneys and are either worthless or harmful, and yet in their published analyses these substances are counted in by the meat-juice vendors as nitrogenous food.

Beef-tea and meat-juice are pleasant to the palate and promote appetite and digestion. They can be used with advantage as flavouring agents, but must not be regarded as real foods. The 'ox in the cup' is a figment of the advertiser's brain, and cannot possibly be obtained by any process whatsoever. By drying meat, it can be reduced

to one-fourth of its weight. Thus a pound of beef-steak can be reduced to $\frac{1}{4}$ pound of dry meat and sold in a form useful for travellers, for so long as the meat is kept dry it will keep good. Water is added to the meat when it is cooked.

Patent foods for infants. The feeding of babies. In the case of patent foods for infants the public are invited in all cases to pay for an inferior article at a great cost, for milk is the only perfect food for young infants; at the same time it is much the cheapest. Now cows' milk varies slightly from human milk. In particular it sets into too close a curd in the child's stomach, and gives rise to indigestion and all the troubles of hand-feeding. The curdling of the milk can be lessened in many ways. The addition of barley or lime water is one of the best means; a little baked flour or boiled bread added to the milk, which is then boiled, will act in the same way. All milk for children should be rendered sterile of bacteria by boiling. This precaution will diminish largely the danger of diarrhoea, and of infectious diseases such as consumption. To infants at the first start milk should be given very dilute (1 part to 3 or 4 of water), being gradually strengthened as they become used to the diet. A patent food may be used with advantage to add to the milk in place of baked flour; it must not be regarded as the real food, but only as a substance used to modify the milk.

Custard puddings, gravy and bread, oatmeal and other grain foods can be given to babies when about eight or nine months old. Children want little meat, and flourish best on milk, puddings, bread, butter, and jam. Hard biscuits and crusts are good for them in order by use to develop the teeth. It should be remembered that little children are as a rule well lined with fat, and have a very vigorous circulation; they therefore do not suffer easily from cold, and want light woollen clothing.

To make them healthy and sturdy give simple food and fresh air, and allow them to go out in all weathers; avoid coddling, over-clothing, and drugging. No infant should be brought up on patent foods alone, for, besides being far more expensive than milk, they are all deficient in fat, and do not contain the proper inorganic salts necessary for the growth of blood and bone. Babies are not able to thrive on the food suitable for adults. An ignorant mother often boasts to the doctor that the baby shares everything she has to eat. An infant cannot be nourished on arrowroot or cornflour made with water, as these substances contain nothing but starch. Swiss tinned milk may be adulterated with too much sugar, thickened with starch, or robbed of its cream. It is, therefore, not so good as fresh boiled cows' milk.

The worker's diet. The diet of a labourer can consist largely of carbohydrates, and need contain only the minimum amount of proteid. During muscular work the output of carbon dioxide is greatly increased, while that of urea, unless the work is excessive, remains unaltered. Energy is liberated in the muscles by the breaking down of the carbohydrate, and not of the proteid part of the complex substance muscle-protoplasm. To build up this substance carbohydrate food is required.

The brain-worker has a less vigorous digestion, and is as a rule better suited by a larger proportion of animal food, for this is less bulky. Every brain-worker knows that he 'can eat anything' when he is away for a holiday and taking vigorous exercise.

The objects of cooking. By cooking, parasites and bacteria in animal food are destroyed and the starch in vegetable food rendered digestible. The food, moreover, is rendered more palatable. Grilled, roast, or boiled meat, light-boiled eggs, and white fish are most easily digested.

Fried and baked meat are less digestible, for the muscle-fibres of the flesh become coated with melted fat, and the latter prevents the action of the gastric juice. A greasy cook is a bad cook.

Nothing is so easily digested as raw animal proteid; thus oysters, raw eggs, milk, and even pounded and minced raw meat are constantly given to invalids. It cannot be maintained that the coagulation of animal proteid by cooking increases its digestibility. The most economical method of cooking, and one too little practised in England, is to cook meat and vegetables together in the form of stews and haricots. The vegetables, such as rice, carrots, turnips, onions, peas, and beans, are thus permeated with the juices and flavour of the meat; nothing is lost in the cooking, and a small piece of meat goes a very long way. In other words, the correct proportion of proteid to carbohydrate and fat is obtained.

Vegetarianism. The bulk of a purely vegetable diet necessary to satisfy man's needs is very great in comparison with that of a mixed diet. A bulky food is a trouble to digest, and therefore ill-suited to a brain-worker, who wants his blood in his brain, and not in his abdomen.

Man is naturally omnivorous. There are few persons who can sustain their health on a strictly vegetable diet. On the other hand, a diet of eggs, milk, cheese, and vegetable food is wholesome and preferable to an *over-diet* of butcher's meat. Vegetable feeders, like cows, have four stomachs; or, like rabbits, have specially dilated intestines suitable for bulky green food. Man has no such structures. The monkeys, like man in structure, are also mixed feeders. Small monkeys eat insects, lizards, and such like, as well as nuts, grain, and fruit. The larger monkeys eat eggs and small birds. Sally, the famous chimpanzee at the Zoo, ate animal food with great satisfaction.

Over-eating. Most of us, however, eat too much animal proteid. To swallow down a solid hunk of beef or mutton is too easy a task. A correspondingly large helping of fish or bird consists largely of bone, and it is owing to these very bones that more time is spent in the eating, and thus the appetite is satisfied before too much has been eaten. Man in old days hunted for his food, and often went fasting. Now he possesses stall-fed sheep and oxen, and thus may frequently overeat, without the previous exercise of hunting. Some of us would be astonished if our exact requirements of food were weighed out before us. Two pounds of bread and three-quarters of a pound of meat would not go so very far when divided for breakfast, dinner, tea, and supper, and yet this, with a little fruit and plenty of plain water, is more than sufficient to maintain a hard working adult in health. It has been shown that both physiologists and soldiers can be kept in vigorous health on half the proteid usually eaten, if the carbohydrates are correspondingly increased in amount.

Over-eating works mischief upon our bodies, gives the organs of digestion needless work, strains the organs of excretion, and lessens the vigour of the brain. Many men used to a luxurious life are enormously improved in health by the hard diet and hard labour of a prison; centenarians are not found among the rich, but among the poor who have all their lives worked hard, and lived frugally. In the wear and tear of modern life, workers should remember that at the same time as they live frugally they should eat well-cooked and nicely served food. Eating is one of the great enjoyments of life, and should be done at regular intervals of time, and without undue hurry. Enjoyment and good fellowship promote digestion, and this in its turn restores the vigour of the brain.

CHAPTER XXV

THE DIGESTION OF FOOD.

THE food taken into the alimentary canal is by the process of digestion broken down into simpler substances and brought into a state of complete solution. It is thus rendered fit for *absorption* and for building the body tissues. The intestinal canal is lined by a layer of columnar cells. On one side of the cells lies the solution of food, on the other side a network of lymphatics and capillaries. Glands pour their secretions into the mouth, the stomach, and upper part of the intestine or duodenum. The secretions contain ferments which act upon the food in such a way as to render it soluble. The intestinal cells lie bathed in the solution of food; their function is to absorb and pass it on into the blood-stream, whence it reaches the tissues and nourishes the whole body.

The fat is first broken down into fine particles and then split into fatty acid and glycerine. Absorbed by the living cells of the intestines the fat is passed on into the lymphatics and enters the blood-stream by way of the thoracic duct. Cooked and coagulated proteid is changed by the digestive juices into a soluble proteid called peptone, and this in its turn is broken down into simpler substances, such as amido-acids. These, during their passage through the intestinal wall, are either converted into albumin and globulin, and as such reach the blood, or enter the blood as amido-acids, and are taken to the tissues and there built up into the different kinds of tissue-proteids.

The carbohydrates, starch, cane-sugar, &c., are converted into soluble grape-sugar and absorbed as such into the blood-vessels. Passing into the mesenteric capillaries, the absorbed sugar and the products of

the digested proteid are carried by the portal vein to the liver. In the liver important processes go on, for in its cells the food is partly stored up and in other ways rendered fitter for the general uses of the body.

The alimentary canal consists of—

(1) The mouth, where the food is chewed, mixed with saliva, and reduced to a condition of pulp.

(2) The gullet, a tube running from mouth to stomach, which affords a passage for the food.

(3) The stomach, a large bag wherein the food can be stored up and digested at leisure.

(4) The small intestine, where the food is completely digested, rendered soluble, and absorbed into the blood-vessels and lymphatics.

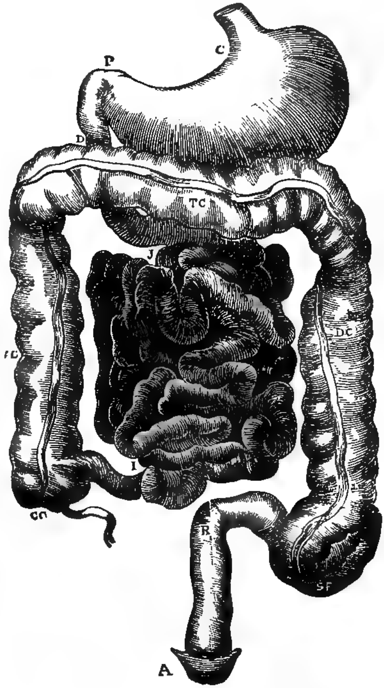


FIG. 95. A. Anus. The intestinal tract removed from the body. AC, TC, DC, SF. Large intestine. C. Cardiac end of stomach. CC. Junction of large and small intestine containing ileo-caecal valve. D. Duodenum. I, J. Small intestine. P. Pyloric end of stomach. R. Rectum.

(5) The large intestine, where the last remnant of nutriment is absorbed, and the waste materials gathered together to be expelled as faeces.

These parts must be severally studied in detail.

The teeth and mastication. The teeth are embedded in sockets in the jawbones, each tooth consisting of a crown

and one or more fangs or roots. In the centre of the tooth there is a hollow full of soft connective tissue containing many blood-vessels and nerves. This is the pulp cavity.

If there be more than one fang the pulp cavity extends down into each, and opens by a small hole at the end of each. The vessels and nerves enter through these openings.

The main substance of the tooth is formed of a hard bony substance called dentine. Little branching tubes radiate through the dentine and convey nutriment to it from the pulp cavity. The dentine at the crown of the tooth is covered with a layer of *enamel.* This is the hardest and densest substance in the body, consisting almost entirely of phosphate and carbonate of calcium and other earthy salts. Dentine, on the other hand, contains about the same amount of animal matter as bone.

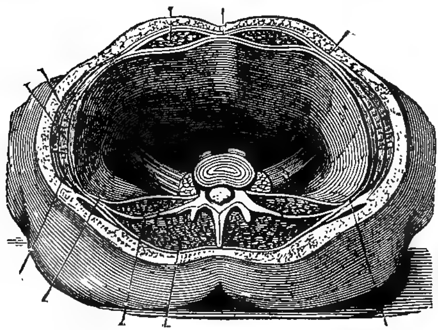


FIG. 96. The trunk of the body is cut across and the viscera removed to show the pelvic basin and the abdominal wall, made of skin and muscle, supporting the viscera. A lumbar vertebra is shown, and the back muscles which lie behind it.

In the growing young tooth a row of living cells is set aside to gather the earthy salts from the blood in the pulp, and to build the enamel. The enamel does not extend over the fangs, but the dentine is there covered by a thin layer of *cement,* which resembles ordinary bone in structure. Each tooth is fixed to the walls of its socket by a fibrous layer containing blood-vessels, and resembling the periosteum of

bone. The decay of teeth is brought about by the action of bacteria; these grow in the particles of food which lodge in the crevices between the teeth. The enamel is destroyed by the chemical substances produced by the growth of the bacteria. Toothache results as soon as inflammation is set up in the pulp cavity, or the nerves therein become exposed to irritation. To avoid decay, the teeth should be kept scrupulously clean, and all cavities filled in by a dentist.

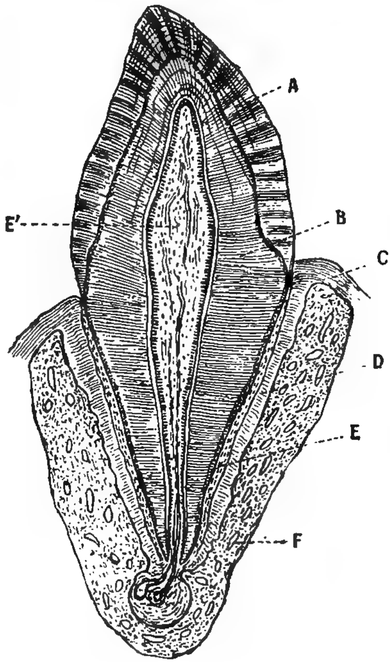


FIG. 97. Section through a tooth. A. Enamel. B. Dentine. C. Gum. D. Vascular connective tissue uniting E, the crusta petrosa of the tooth, to F, the jawbone. E′. Pulp containing blood-vessels and nerves.

The process of mastication, or breaking down of the food by the teeth, is of no little importance, for the ferments of the digestive juices are thereby enabled to reach all parts of the same. A lump of cheese or hard-boiled egg, swallowed whole, can be digested with difficulty, for the juices are not able to soak into so dense a mass, and can attack it from the outside only. Food should not be bolted, but well masticated and mixed with saliva.

The mouth. The mouth is lined with mucous membrane. The surface of this membrane is formed by layers of cells four or five deep arranged in strata over one another. This kind of cell-layer is the same

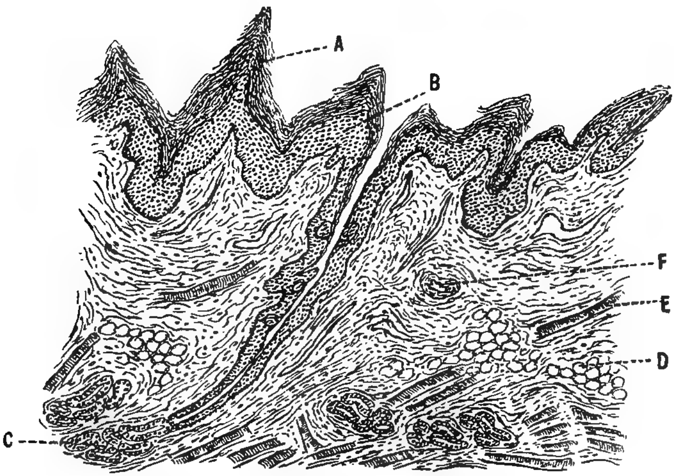


FIG. 98. Microscope, low power. Section through a fragment taken from the front of the tongue. A. Papillae formed of stratified horny cells. B. Soft growing cells. C. Mucous gland; the duct opens on the surface of the tongue. D. Fat-cells. E. Striated muscle-fibres. F. Artery.

as that met with in the skin, and is called *stratified epithelium.* As the skin folds over at the lips it becomes continuous with the moist mucous membrane of the mouth. The deeper cells of the stratified epithelium are cubical or columnar in shape. The superficial cells are produced by the multiplication of the deeper ones, and are flat and horny. These horny cells protect the softer tissues within from friction. They become rubbed off, and are constantly renewed.

Take a drop of mucus from the mouth and examine it under the microscope (high power); you will see many of these flat horny cells.

Below the stratified epithelium there lies a soft bed of connective tissue containing blood-vessels and nerves, and in this are many little gland-tubes which open by minute ducts into the cavity of the mouth. These secrete mucus. The pharynx and gullet are lined with exactly the same kind of mucous membrane.

The tongue is a muscular organ covered with stratified epithelium. The latter is raised into little processes or papillae which give the tongue its roughness. In some of these papillae lie the sense-organs of taste. The appearance of the mucous membrane of the tongue is a sign of value to the doctor. It tells him whether the alimentary canal be in a healthy state or in a condition of irritability or catarrh.

The glands in general. At this point the general structure and nature of the different glands in the body may be discussed with advantage. You have already studied the structure and function of the lymphatic glands. These produce white blood corpuscles, destroy bacteria, and work upon the chemical nature of the lymph. There are other glands in the body, such as the *spleen*, the *supra-renals*, and the *thyroid*, which in one way or other alter the nature of the blood. These are ductless glands, and their function is termed *metabolic*.

The function of another set of glands is to form and separate from the blood certain important fluids. Some of these secrete digestive juices in the alimentary canal, others excrete waste products out of the body. All glands of this kind possess ducts. The salivary glands secrete saliva in the mouth, the gastric glands pour gastric juice into the stomach, the pancreas yields pancreatic juice to the duodenum, and these juices effect the processes of digestion.

The liver secretes bile, and the bile partly aids in the digestive process, and is partly an excretion. Out of the bile which enters the duodenum certain waste substances are expelled in the faeces. The kidneys excrete urine, a waste product, and the sweat-glands sweat. At the same time as these glands form their particular fluids many of them exert an important influence on the quality of the blood. Thus the liver, the kidneys, and the pancreas have important metabolic functions.

The structure of glands. The simplest form of gland is a single cell which produces and expels a secretion. The whole of the stomach and intestines are lined with columnar cells, and among these are scattered numerous cells, each of which elaborates a fluid called mucus. The protoplasm of such a cell becomes distended with the secretion, and finally the cell bursts open and discharges the mucus into the intestinal canal. All over the inner surface of the stomach and intestines there are in addition numberless little pits. These are the ducts of tiny glands. Each gland, shaped like a test-tube, is lined with secreting cells, and the secretion escapes out of the tube into the intestinal canal. In the stomach and duodenum the gland-tubes are slightly more complex than those in the small or large intestine, for each duct branches into two or three short, coiling tubes lined with secreting cells.

In the larger glands, such as the pancreas and salivary glands, there is a main duct which branches into lesser ducts, and these into still smaller ducts, and so on. The smallest ducts of all open into tubes or sacs lined with secreting cells, and the whole structure resembles in miniature a bunch of grapes. The stalk of the bunch is the main duct, the branches of the stalk the little ducts, and the grapes the secreting sacs. Owing to this resemblance such glands are termed *racemose.*

It is on this principle that all the large secreting glands are built, and since all the branching ducts and secreting sacs are closely knit together by connective tissue each gland forms a more or less compact mass.

The glands are richly supplied with blood-vessels, for the capillaries twine in a close network round the secreting sacs or *alveoli*. From the blood within the capillaries the gland-

FIG. 99. Microscope, low power. A salivary gland unravelled to show the duct branching and ending in little sacs or alveoli.

cells draw certain substances, and out of these manufacture their secretion. Nerves enter the glands, and the nerve fibrils end in contact with the gland-cells, and the secretion is brought under control of the central nervous system.

The gland-cells are found to undergo certain changes during rest, or after a period of active secretion. During rest, the cells become crowded with granules, and during active secretion these granules pass out of the cells and disappear into the ducts. The granules can be seen if a fragment of fresh pancreas be teased with needles on a glass slide and examined with the high power of the microscope.

The salivary glands. There are in all six salivary glands, three on each side of the mouth. Two parotid glands—these lie one on each side just in front of the ear and behind the angle of the jaw. The duct of each parotid gland opens on the inner surface of the cheek. Two submaxillary glands—these lie one on each side under the lower jaw; the duct of each opens under the tongue, and there, in some people, the saliva may be seen welling up. The two sublingual glands lie under the tongue and have several little ducts—they are the smallest in size. In addition to these six big glands there are a great number of little ones situated in the mucous membrane of the mouth and tongue, all of which help to swell the volume of the saliva. The taste, smell, or even thought of food causes saliva to flow into the mouth. The glands are under control of nerves which, on excitation, not only excite the cells to secrete, but cause the blood-vessels of the gland to dilate and become turgid with blood. The taste of food excites sensory nerves in the mouth; these carry the impulse to the spinal bulb, and from thence a message is despatched to the salivary glands ordering them to secrete. At the same time the blood-vessels supplying them are commanded to dilate so that the glands may have plenty of blood at their disposal.

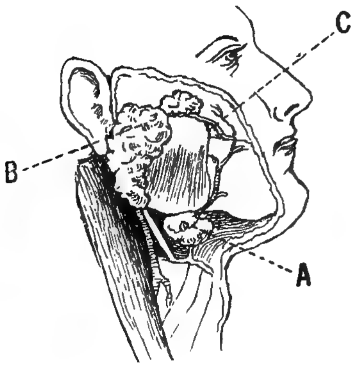


FIG. 100. Dissection of the face to show salivary glands. A. Submaxillary glands. B. Parotid gland. C. Duct of parotid gland.

According to the nature of the sensory excitation does the brain cause an appropriate amount and kind of secretion. Thus, if stones be put in a dog's mouth, no secretion results. The dog rolls them out with his tongue. If sand be put in watery saliva flows and washes the sand out. If bread be put in, a saliva is secreted containing plenty of ferment to digest the starch in the bread. All this control is carried out by the lower brain centres, without the action of consciousness.

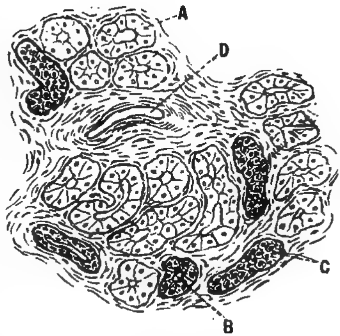


FIG. 101. Microscope, high power. Section through a fragment of submaxillary gland. A. Alveoli with mucous cells. B. Duct. C. Alveoli with granular cells. D. Blood-vessel in the connective tissue which surrounds the alveoli.

Action of saliva. Make a thin solution of starch by boiling a little in some water. When this has cooled, test some of it with iodine:—a blue colour is obtained. Now take another sample of the starch solution and hold it in the mouth for a minute. Then returning it to the test-tube, test again with iodine:—no blue colour is obtained. Repeat the operation with a third sample, and add to this some caustic potash and a little copper sulphate until a deep blue solution is produced, and then boil:—a yellow-red precipitate will appear, indicating the presence of sugar. Saliva therefore changes starch into sugar, and the kind of sugar that is formed is malt-sugar or *maltose*. Saliva will not act on raw starch, because the granules of starch are protected by a tough external coat, and thus a cooked potato is much more digestible than a raw potato, and rice, tapioca, &c., are always cooked, and not eaten raw.

Composition of saliva. Saliva is a watery, alkaline fluid, and contains salts, carbon dioxide gas, mucus, and a ferment called *diastase* or *ptyalin*. About two pints of saliva are secreted in the course of a day. Mucus is a slimy, viscid proteid substance, and gives the proteid test:—a

yellow colour on boiling with nitric acid. It is precipitated from saliva by the addition of vinegar or acetic acid.

Mucus and ptyalin are manufactured by the salivary cells: ptyalin is a ferment which changes the starch into sugar. Just as yeast-cells, by their growth in sugar, produce alcohol and carbon dioxide gas, and thus act as a ferment, so the salivary cells produce ptyalin, which turns starch into sugar. The difference between yeast or bacterial fermentation and that produced by glands is that the cells of the latter do not, like the former, actually grow in the food and produce fermentation by their growth. In place of this the gland-cells secrete a substance which produces fermentation. This difference is not great, for by special means a substance has been isolated from yeast which, in the absence of all living yeast-cells, turns sugar into alcohol.

The digestive ferments such as ptyalin are extraordinary substances, for they exist in the minutest quantity, and yet are able to change the nature of large quantities of food. They are destroyed by boiling, and are most powerful at body temperature, acting very feebly in the cold. Ptyalin will only act in a faintly alkaline or neutral fluid, and is destroyed by acid.

The pharynx and gullet. The pharynx is lined with the same mucous membrane and stratified epithelium as is the mouth, and this is continued down the gullet to where it opens into the stomach. Many small mucous glands lie beneath the epithelium in the deeper part of the mucous membrane; little ducts pass from these and pour their secretions into the tube and so keep it moist. These glands enlarge and produce trouble in relaxed conditions of the throat. Into the pharynx there are seven openings—the two posterior openings of the nose, the two Eustachian tubes which connect the pharynx with the middle ear, the mouth, the gullet, and the windpipe.

The gullet is about nine or ten inches long, and runs down into the thorax behind the windpipe. Passing through

the thorax it pierces the diaphragm and enters the stomach. The gullet, like the pharynx, is a soft flaccid tube lined with mucous membrane inside, and covered with a coat of muscle outside. It has no cartilaginous rings, and thus differs from the windpipe.

Swallowing. The food, having been broken up by the teeth and mixed with saliva, is gathered up by the tongue

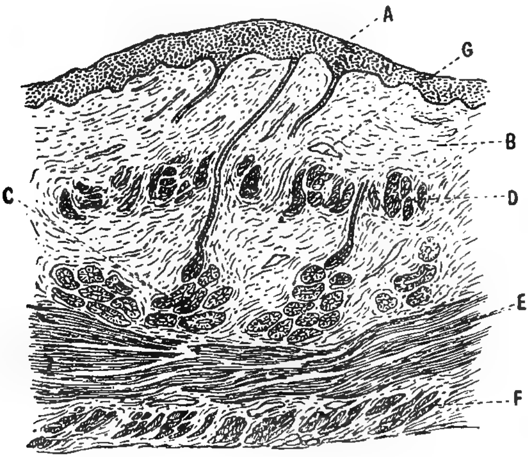


FIG. 102. Microscope, high power. Section through a piece of the wall of the gullet (oesophagus). A. Stratified cell-layer. B. Soft connective-tissue coat. C. Mucous glands with ducts. D. Muscular fibres. E and F. Circular and longitudinal muscular coats. G. Blood-vessel.

into a mass or bolus and forced between the pillars of the fauces into the pharynx. At the same moment the windpipe is drawn upwards, so that the epiglottis covers the opening into the larynx, and the respiration temporarily ceases. Owing to these precautions food does not gain an entrance into the windpipe. If by chance any does go 'down the wrong way,' it excites violent coughing, and is thereby expelled. The muscles at the floor of the mouth contract and force the tongue backwards like a piston, driving the food before it into the pharynx.

So soon as the blood enters the pharynx, the muscles of this tube contract and close round upon the bolus. Since the latter cannot pass back into the mouth or up into the nose, owing to the contraction of the pillars of the fauces and the elevation of the soft palate, it is forced into the gullet, thence it is passed downwards by a wave-like contraction of the muscular wall. Each part of the gullet contracts in its due turn after the part above, and thus forces the food lower and lower until it reaches the stomach.

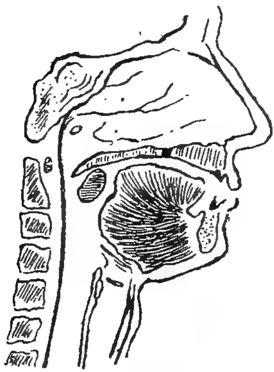


FIG. 103. Diagram to show a bolus of food being pushed into the pharynx by the tongue.

The delicate mechanism of swallowing is controlled by nerves. The sensory nerves, stimulated by the presence of food, carry messages from the mouth and throat to the spinal bulb, and there excite the motor nerves, which set the muscles of the pharynx and gullet in action. After the tongue has delivered the bolus to the pharynx, the process of swallowing becomes involuntary, and cannot be arrested by the will. Owing to the grasping action of the muscles by which the food is swept onward, a man can drink and eat when standing on his head.

In taking a long draught of water, we may swallow so quickly that the liquid falls down into the stomach in a continuous stream. The muscles of the gullet during this operation remain at rest, and the wave of contraction follows the last gasp only. If you place your ear against the back of a person who is thus swallowing, you can hear the liquid falling into the stomach. The danger of a child swallowing a large bone or other hard substance is that it may, by sticking in the gullet, compress the windpipe,

which lies in front of it. Such a mishap produces vomiting, by which the offending substance is expelled upwards. The fear of choking from bones is widespread, but fortunately such a death is exceedingly rare.

The stomach. The gullet opens into the stomach, a large bag situated just below the diaphragm. The stomach is of a peculiar shape, as shown by Fig. 95. The large dilatation or *cardiac* end lies on the left side of the abdomen, while the narrower part to the right is the *pyloric* end. The latter part is covered over by the liver. The gullet opens into the top of the cardiac end, while the pyloric end opens into the duodenum by a narrow orifice. The stomach is a muscular bag, and at the pyloric orifice the muscle forms a thickened band which, by contracting or dilating, regulates the passage of food into the duodenum.

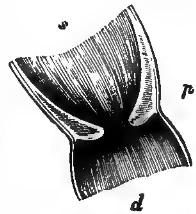


FIG. 104. *d.* Duodenum. *p.* Pyloric sphincter. *s.* Stomach.

Most people who complain of a pain over the heart really have indigestion, and in indicating the seat of the pain, place their hands not over the heart, but over the stomach. Disease of the heart does not produce pain over the region of the heart, and the knowledge of this fact may relieve many of groundless fears. It is a curious fact that the disease of an internal organ, such as the stomach, produces what is termed a reflected pain and tenderness in a particular area of the skin. Each organ likewise produces pain and tenderness in some particular part; for example, the cutting of a wisdom tooth often produces a feeling of sore throat. Reflected pains are caused in this way. Suppose the nerves of the stomach are irritated, the irritation spreads up the stomach nerves to the thoracic part of the spinal cord, and thereby exciting the nervous tissue throws it into a state of over-sensitiveness. Thus any impressions which stream into the same part of the spinal cord from the

skin will be felt acutely. On the same principle, by applying a poultice or blister to the skin in the tender parts, the diseased organ may be benefited. The stomach and intestines are suspended by the mesentery from the walls of the abdomen. The inner lining of the abdominal cavity is called the *peritoneum* : this rises up from the wall in a thin sheet, and, passing to the stomach and intestines envelops them.

Obtain from a butcher the stomach of a freshly killed pig. Owing to the investment of peritoneum, the stomach is on the outside smooth and glistening. On cutting open the stomach it will be found thrown into folds. The inner lining or mucous membrane is loose and becomes wrinkled up when the stomach is empty, contracted and smoothed out when the organ is full of food and dilated. Between the mucous membrane and the peritoneum lie bands of spindle-shaped muscle-cells, which form the muscular coat.

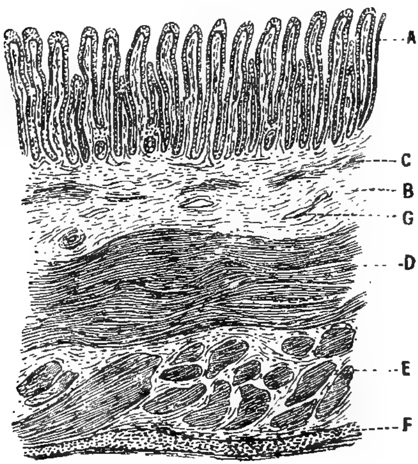


FIG. 105. Microscope, low power. Section through a fragment of the wall of the stomach. A. Glands. B. Soft connective tissue. C. Muscle-fibres in B. D, E. Circular and longitudinal muscle coats. G. Blood-vessel.

Throughout the whole of the alimentary canal, from the stomach to the anus, there run the same three coats, namely, mucous membrane within, muscle in the middle, peritoneum on the outside. The mucous membrane is bound to the muscle-coat by loose connective tissue. In this lie blood-vessels and nerves which send branches to supply the

glands of the mucous membrane on the one side and the muscle-coat on the other side.

A layer of columnar-shaped cells forms the innermost lining of the stomach, and many of these become swollen and discharge mucus. This layer dips down into innumerable little pits, which can be seen if the inner surface of the pig's stomach be examined with a magnifying-glass. The pits are the ducts of the glands. The glands are little blind tubes arranged side by side in the mucous membrane like a number of test-tubes. The mouths or ducts of the glands are lined with columnar cells, while the gland-tubes are lined with somewhat cubical-shaped cells, which become filled with granules of secretion. On the outside of these cells, but only in the cardiac end of the stomach, there lie some larger oval cells, which also pour their secretion into the gland-tubes. From these gastric glands the gastric juice is secreted. When empty, the stomach is pale in colour, but so soon as food enters it, or even at the taste or sight of food, the mucous membrane becomes flushed with blood, and drops of juice begin to trickle out of the glands. These changes are brought about, as in the case of the salivary secretion, by nervous influence.

The changes that take place in the stomach were first carefully observed by Spallanzani and later by Beaumont. Spallanzani enclosed meat in perforated metal balls and both swallowed them himself, and gave them to birds of prey, such as owls. Those he eat himself he recovered from his excreta. The owls vomited up their share with the bones of their last meal. He examined the changes the meat had undergone. Beaumont's subject was a Canadian who, as a result of a wound, had a permanent opening into his stomach. Beaumont took the man into his service, kept him for years, and determined by careful observation many important facts about the digestion of food.

Composition of gastric juice. The gastric juice can be

obtained by swallowing one end of a rubber tube—a stomach catheter—and drawing off the contents of the stomach by means of a syringe. Such an apparatus is called a stomach-pump. On waking in the morning a test meal is swallowed, say of egg and biscuit, and an hour later the contents of the stomach are withdrawn. Beaumont collected the juice from the hole in the stomach of his Canadian servant. It is a colourless fluid, consisting of water, with a little *hydrochloric acid,* and two ferments in solution, and a small amount of salts. The ferments are called *pepsin* and *rennin.* There are about two parts of hydrochloric acid in every 1000 parts of juice, but this is enough to render the juice distinctly acid.

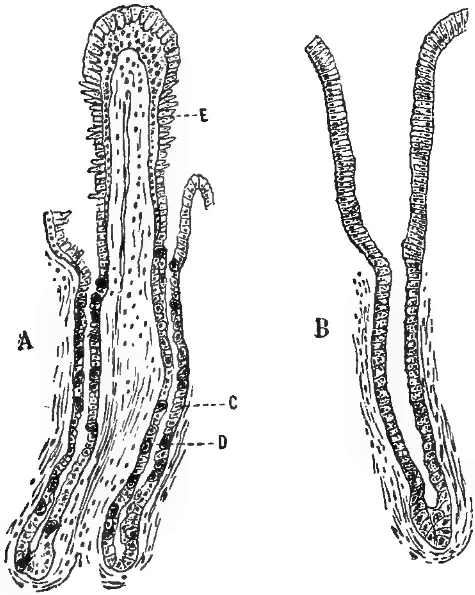


FIG. 106. Microscope, high power. Gland-tubes of the stomach. A. Cardiac; after Stöhr. B. Pyloric gland. C. Cells which are supposed to secrete pepsin. D. Cells which are supposed to secrete hydrochloric acid. The pyloric glands only contain pepsin salts. E. Columnar cells.

The action of gastric juice. Scrape off the mucous membrane of the pig's stomach, mince it up finely, and adding some dilute hydrochloric acid (two parts in 1000 of water), leave it to soak in a warm place for some hours.

Finally, strain off the fluid through muslin. This will contain the digestive ferments.

Take some egg-white in a test-tube and add to it *one* drop of copper sulphate solution and some caustic potash, when a violet colour will result. This is a characteristic test for albumin and globulin.

To another sample of egg-white add some of your artificially prepared gastric juice, and keep the test-tube in water warmed to such a temperature as the hand can bear with comfort. After half an hour test this with a drop of copper sulphate solution and caustic potash; a rose-red colour will be obtained in place of violet. This is a characteristic test for *peptone.*

A piece of cooked meat or hard-boiled egg can be digested at the same time. The piece will be found to gradually disappear. It changes into soluble peptone. If raw egg-white be placed in a bladder, and the latter be immersed in water, the proteid will not diffuse through the membrane. Let egg-white be digested with gastric juice and turned into peptone; the latter, on being placed in the bladder, will diffuse through, and after some hours the water surrounding the bladder will yield the pink colour test characteristic of peptones. Next add some of the prepared gastric juice to a solution of boiled starch and some to a little oil: no change will be brought about in these substances. The starch will continue to give a blue colour with iodine, and the oil will remain unaltered in appearance.

Finally, purchase some rennet. This is an extract of calf's stomach. Add some to milk warmed to body temperature. The milk will clot and form a junket. Junket when eaten with stewed fruit forms a pleasant and nutritious food. It is owing to the ferment rennin in its stomach that a baby, when it vomits, returns its milk curdled.

When the food, which has been broken up by the teeth and mixed with alkaline saliva, reaches the stomach, the ptyalin ferment continues to act upon the starch for some little time. The food which entered the stomach first is in contact with the stomach wall and absorbs the gastric juice, while the food which entered last lies in the middle, and is acted on by the saliva. So soon as the gastric juice is

secreted in sufficient amount to make the food acid, the ptyalin is destroyed and the pepsin comes into action.

The muscular coat of the stomach contracts in such a way as to move the food towards the pyloric opening. This remains shut so long as undigested masses of food press against it, but opens and allows the *chyme* to pass through into the duodenum. The chyme is the name given to the food in the stomach when, after two or three hours' digestion, it is reduced to a pulpy and almost fluid condition.

Pepsin is a ferment which can only act in the presence of weak acid. Bacteria may grow in the stomach, and setting up the wrong kind of fermentation, produce thereby the evolution of gas, distension of the stomach, and flatulence. The hydrochloric acid secreted by the healthy stomach naturally acts as an antiseptic and restrains the growth of bacteria. Thus a dead frog keeps sweet in the stomach of a snake for many days while it is slowly digested.

The stomach, like any other organ, requires periods of rest. Meals should be taken at regular times, and nothing should be eaten between meals. During digestion, plenty of blood is required in the abdomen, and therefore the after-dinner hour is not a suitable time for brain-work.

Some of the food, while in the stomach, is absorbed into the blood-vessels, and this helps to excite the secretion of gastric juice. The products of proteid digestion and sugar pass through the lining membrane into the capillaries which surround the gastric glands in a close network. Alcohol is rapidly absorbed from the stomach, and many drugs; but water, curiously enough, is scarcely absorbed here, but passes on into the intestine.

Absorption even takes place from the mouth, and thus powerful drugs or poisons may very rapidly get into the blood.

Vomiting. In vomiting, the opening into the larynx is shut, and the stomach compressed by a violent expiratory

effort; at the same time the pyloric orifice is closed, while the orifice into the gullet is opened. The contents of the stomach are thus expelled out of the mouth. The act of vomiting is usually produced by irritation of the stomach, but may result from irritation of other abdominal organs, or of the brain itself. In cases of poisoning, vomiting can easily be produced by tickling the fauces with the finger, or by a teaspoonful of mustard in a glass of warm water.

The pancreas. When the chyme passes out of the stomach into the duodenum, it meets with two juices—the pancreatic secretion and the bile. The pancreas lies behind the stomach, in the bend formed by the duodenum. It is a long racemose gland, and may be obtained from the butcher under the name of sweetbread. There are two kinds of sweetbread—the thymus gland or heartbread, and the pancreas.

The thymus gland is in structure like a lymph gland, and lies at the top of the heart, beneath the sternum. It is only found in young animals, as it shrivels up in later life, and becomes of no importance. Its function is unknown.

The pancreas consists of a great number of secreting tubes which open into ducts. The ducts join together to form one main duct, and this, joining with the bile-duct coming from the liver, pierces the wall of the duodenum.

Pancreatic juice. The pancreatic juice is a colourless alkaline fluid. It contains a little proteid, salts, and three ferments. The chief salt is sodium carbonate, which renders the juice alkaline. Of the three ferments, one acts upon starch changing it into sugar, the second changes proteid, and the third splits up fat into fatty acid and glycerine. The pancreatic ferments will only act in the presence of dilute alkali. The acid chyme passing into the small intestine acts upon the mucous membrane and causes, therein, the formation of a substance called *secretin*, which passing into the blood is carried to the pancreas and there excites the

secretion of pancreatic juice. Thus while the products of salivary digestion entering the blood in the stomach excite the secretion of gastric juice, the products of gastric digestion similarly excite the secretion of pancreatic juice. When the pancreatic juice enters the intestine the ferment trypsin is not active. It is made so by the interaction of the pancreatic juice with the intestinal juice.

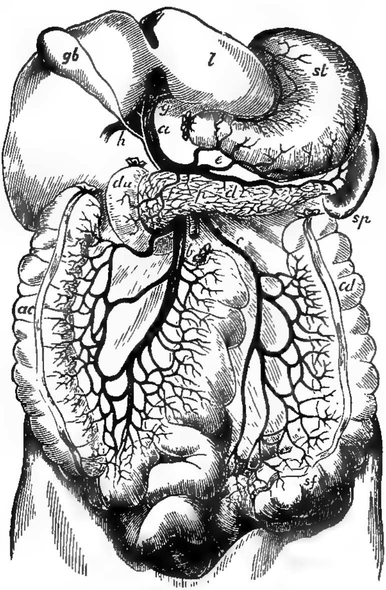


FIG. 107. Abdominal viscera displayed so as to show the portal vein carrying the blood from the viscera to the liver. *l*. Liver. *gb*. Gall-bladder. *st*. Stomach, and *du*. Duodenum. These have been divided from each other. *p*. Pancreas. *sp*. Spleen. *ac*, *cd*. Large intestine. The bile duct is shown sending off a side branch to the gall-bladder on its way to the duodenum.

Obtain the pancreas of a pig from a butcher. Chop it up and soak it in a weak solution of sodium carbonate (one part by weight in 100 of water). Keep the mixture warm for some hours, and finally strain off the liquid.

Add some of this artificial pancreatic juice to egg-white or a piece of meat, and keep it at blood heat for half an hour. The ferment named *trypsin* will dissolve and change raw or coagulated proteid first into soluble peptone and later into amido-acids, &c. Test with a drop of copper sulphate solution and caustic potash:—a rose-red colour will be obtained. If the digest be kept warm for twenty-four hours it gives off a horrible smell owing to decomposition of the proteids.

Add some of the juice to a solution of starch, and keep this also at body temperature. The starch will be turned by the ferment *diastase* or *amylopsin* into sugar. Test with iodine—no

blue colour will result, while on boiling another sample with caustic potash and copper sulphate, a yellow-red precipitate will be obtained.

Steapsin is the name given to the fat-splitting ferment. It can only be extracted by soaking a perfectly fresh pancreas in weak sodium carbonate solution. On adding some of this extract to pure oil, soap is formed by the union of fatty acid and alkali, and at the same time the oil is emulsified, that is to say, it is broken up into tiny particles, and becomes white like milk.

Composition of bile. The bile-duct, bringing the bile from the liver, joins the pancreatic duct. The acid chyme, as it passes over the orifice of these two ducts in the duodenum, excites certain afferent nerves, which reflexly cause a flow of bile from the gall-bladder. The bile and pancreatic juice neutralise the chyme, and the flow of these juices then ceases till more acid chyme comes in. The bile-duct, on its way from the liver, gives off a side branch to the gall-bladder. This is a little bag in which the bile is stored until it is required for digestion. It lies in contact with the liver at its lower margin, and is dark green in colour.

The bile is golden-yellow or yellow-green in colour. It is an alkaline fluid, and contains some peculiar *bile salts*, which are composed of sodium combined with complex organic acids. A curious fatty-looking substance called *cholesterin* can also be crystallised out of bile. Cholesterin is found in all animal cells, and belongs probably to a class of chemical bodies called terpenes which are widely spread in plants, but of whose function we know nothing. There is also in bile a complex fatty substance called lecithin, which is also a constituent of animal cells. On decomposition lecithin yields fat, phosphoric acid, and a nitrogenous base called cholin. The gall-bladder secretes mucus, which makes the bile viscid and slimy. The colour of the bile is due to a pigment (*bilirubin*) which is derived from haemo-

globin, and thus is a waste product of the red corpuscles of the blood. It is this pigment which, after undergoing a change in the intestines, colours the faeces. The colour of the urine is also derived from the bile pigment. Sometimes the bile-duct gets temporarily plugged up by thick mucus, and jaundice then results. The bile, secreted by the liver, is absorbed into the blood, as it cannot escape into the intestine, and the man becomes yellow in colour. At the same time the faeces become very pale, owing to the absence of bile, while the urine becomes high-coloured, owing to its presence.

FIG. 108. The duodenum cut open so as to show the bile-duct (*a*) and the pancreatic duct (*b*) opening by a common orifice.

Obtain some bile from the butcher. Observe its colour and slimy nature. Pour some into a white basin, and add to this a few drops of strong fuming nitric acid. A wonderful play of colours will result. This is a characteristic test for bile pigment. Wash out a basin with bile. Add a little solution of cane-sugar and sulphuric acid. On warming, a beautiful purple colour results. This is a test for bile-salts.

Action of the bile. The bile contains no ferments. Warm bile is able to dissolve a large quantity of fatty acid, and some of the fatty acid set free by the pancreatic ferment, steapsin, is thus dissolved, while another portion unites with the alkali of the bile and pancreatic juice to form soluble soap. By means of these juices the fat is broken up into soluble fatty acid, soap, and glycerine. The lecithin and bile salts help greatly in the solution of the fatty acids.

Very little fat is absorbed in cases of jaundice, showing that the bile is of especial importance in the digestion and absorption of fat. The bile pigment and cholesterin are

excreted in the faeces, but most of the bile-salts are re-absorbed.

Structure of the small intestine. The first part of the small intestine is called the duodenum: it is almost 12 inches long. Here the chyme, on escaping through the pyloric orifice, mixes with the bile and pancreatic juice. After this the food is no longer termed chyme, but *chyle.* The rest of the small intestine is almost twenty feet long, and lies in coils in the abdomen suspended by the mesentery. At the junction of the small with the large intestine, there is a fold of the mucous membrane which acts as a valve and permits the material to pass only in one direction, namely, from the small into the large intestine (see Fig. 114).

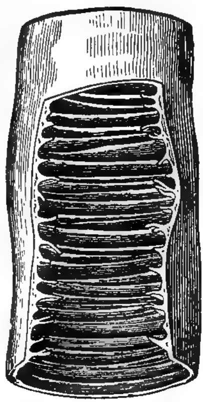


FIG 109. A piece of small intestine cut open to show the valvulae conniventes.

There is at this point a little blind tube opening out of the intestine. It is called the *appendix.* It is a rudiment of a part of the intestine which is of importance in herbivorous animals. In man, it is sometimes the seat of troublesome and dangerous inflammation.

The wall of the small intestine is composed of a mucous membrane within, and a muscular coat without. The latter, in its turn, is covered with the peritoneum, which passes into the mesentery, and so forms the attachment by which the intestine is suspended from the abdominal wall. In the fold of the mesentery there run the mesenteric arteries, which, arising from the aorta, end in capillaries in the wall of the intestine. The blood gathered up from these capillaries passes into the mesenteric veins, and these join together to form the portal vein, which, entering the liver, breaks up into a set of capillaries there.

The stomach, large intestine, pancreas, and spleen are supplied with blood in the same way. Thus all the blood that circulates through these organs passes to the liver, and percolates through that organ before it reaches the vena cava inferior.

In the mesentery there run also numerous lymphatics or *lacteals*, as they are here called. These issue from the intestine. If a cat were killed an hour or two after it had been given a meal of milk, and the abdomen were opened, the lacteals would appear full of milky white fluid. This is the fat which has been absorbed from the intestine. The white fluid could be traced from the lacteals into the thoracic duct, and from thence to where the latter opens into the veins at the root of the neck. There are many lymphatic glands in the mesentery, and the fat percolates through these on its way to the thoracic duct, and some of it is no doubt utilised by the lymph-cells.

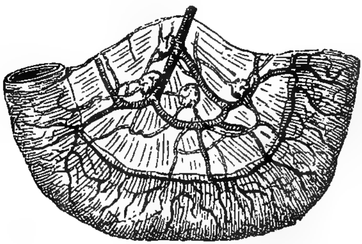


FIG. 110. Loop of small intestine, showing the absorbents, i.e. branches of portal vein, and lacteals with lymphatic glands on the course of the latter.

On opening the small intestine of a rabbit, the mucous membrane will be seen to be thrown into regular folds which circle round the wall. These folds are called the *valvulae conniventes*, and by their means the absorbing surface of the mucous membrane is enormously increased. The mucous membrane, on close inspection, appears like the pile of velvet. This is so, owing to the fact that the mucous membrane rises up into numberless little finger-shaped processes called *villi*.

Each villus is covered with columnar cells, many of which secrete mucus. Between the villi, little pits open which lead into gland-tubes called the *glands of Lieberkühn*.

The mucous membrane of the small intestine is thus

folded in a most remarkable manner. It is thrown into the big folds—the valvulae conniventes; these are studded with little folds—the villi; and, between the villi, the membrane forms the glands of Lieberkühn.

In the duodenum some of the gland-tubes are long and branching; these are known as *Brunner's glands*. Surrounding the glands and running up in the centre of each

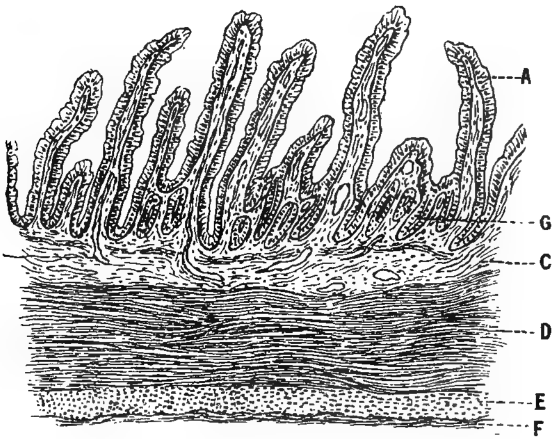


FIG. 111. Microscope, low power. Section through a fragment of the wall of the small intestine. A. Villi lined with columnar cells. C. Soft connective tissue with muscle-fibres and blood-vessels. D and E. Circular and longitudinal muscle-coats. F. Peritoneum. G. Glands of Lieberkühn.

villus are soft films of connective tissue, and in this tissue lie the blood-vessels, lymphatics, and nerves.

A close network of capillaries and a lacteal are allotted to each villus. The layer of columnar cells which covers the villus separates the food within the intestine from these vessels. Through this layer of cells, absorption takes place.

The muscular coat of the intestine consists of bands of spindle-shaped muscle-cells: some of these run circularly round the intestine, and others lengthwise. A few muscle-fibres run up into each villus.

The muscular coat is supplied with a network of nerve-fibres, and some of these fibres end in branches round the gland-tubes: this arrangement of nerves is the same in all parts of the alimentary canal.

The muscle contracts in a wave-like fashion. As the wave of constriction ripples slowly down the intestine it forces the food onwards towards the large intestine. This kind of contraction is known as *peristalsis.* Irritation of the intestine at any point causes the gut to contract above that point, while below it becomes relaxed. If the abdomen be opened in a freshly killed animal, the intestines may be seen to writhe like a bag of worms. The swaying movements keep the contents moving up and down, while the peristaltic movements, at times, force them onwards. The movements of the intestines not only forces the contents downwards, but also helps to empty out the absorbed food both from the lacteals into the thoracic duct and from the capillaries into the portal vein.

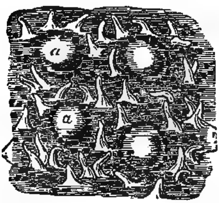


FIG. 112. Peyer's patch, as seen with a magnifying-glass. *a.* Lymph nodules. The villi and openings of the crypts of Lieberkühn are also seen; the latter appear as dots.

If, from irritation, the peristalsis become very violent, griping pain is produced, as in diarrhoea; the contents are then hurried down and expelled in a liquid state.

Here and there, lying beneath the mucous membrane of the intestine, are little masses of lymph-cells supported by a meshwork of connective tissue. These are *lymphoid nodules.* In the lower part of the small intestines the nodules are grouped together into white patches called *Peyer's patches*, each about ½ or 1 inch long. The nodules are only covered with columnar epithelium, for just over these the villi and glands of Lieberkühn are present. The lymph-cells guard the body from the invasion of bacteria which swarm

in the lower part of the intestines. In typhoid fever, the bacteria invade the Peyer's patches and cause ulceration there.

The milky fluid absorbed by the lacteals of the villi percolates through the lymphoid nodules before reaching the lacteals of the mesentery. In the mesentery, it passes through the lymph-glands situated there. The fluid is thus submitted to the action of the lymph-cells before it enters the thoracic duct and reaches the blood stream. Some of the fat is withdrawn and taken up into the protoplasm of the lymph-cells, while many of these cells escape

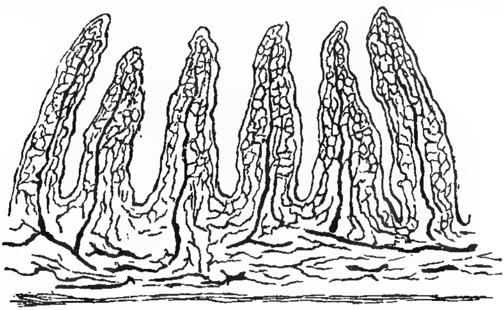


FIG. 113. Microscope, lower power. Section through the small intestine showing the network of capillaries in the villi.

into the fluid within the lacteals, and so, by entering the blood, keep up the supply of white corpuscles.

Functions of the small intestine. The great function of the small intestine is to absorb the food, the digestion of which has been completed by the bile and pancreatic juice. The columnar cells which line the wall have the special task of absorbing, and since they must absorb sufficient food for the whole body, the small intestine is not only very long, but its absorbing surface is enormously increased by the valvulae conniventes and villi.

The columnar cells have the power to take up the pro-

ducts of proteid digestion, sugar, fat, salts, and water, and to pass these substances on into the capillaries or lacteals. By some mysterious process the fat is directed to the lacteals, the sugar and proteid products to the capillaries.

The food substances are turned into a soluble form, for in this form they must be more readily absorbed, but the evidence is strong to show that the process of absorption is not one of simple osmosis, but depends on the living power of the columnar cells. The sugar, peptone, salts, and water do not pass through the living intestinal wall in anything like the proportions or rate with which they would permeate if placed in a bladder suspended in a bath of blood.

Moreover, the columnar cells change the nature of the digested food passing through them. They probably change some of the peptone and amido-acids which they absorb, and deliver to the blood albumin and globulin, the proteids which are naturally found in blood, while some of the amido-acids and polypeptides are absorbed as such and are dealt with by the liver and other organs. There is strong proof to show that the columnar cells absorb the glycerine and fatty acid set free in the intestine by the action of the ferment steapsin, and compound these substances together into fat. Thus, during absorption of a fatty meal, the columnar cells become studded with minute drops of fat, and these are passed on into the lacteals. Soap formed in the small intestine during the digestion of fat is probably also compounded with glycerine by the action of the columnar cells. Fat is thus formed, and the alkali of the soap returned to the intestine to assist in the formation of more soap.

The tubular glands of the small intestine secrete a small amount of intestinal juice, there is a ferment in it which has the power to turn cane-sugar and malt-sugar into grape-sugar; and another which has also the power to complete the splitting of the proteids into amido-acids.

The saliva and pancreatic juice change starch into malt-

sugar, and we eat largely of cane-sugar; but in the intestine the sugar, whatever its nature, becomes either grape-sugar or fruit-sugar (dextrose and levulose), and enters the blood as such.

Structure of the large intestine. The wall of the large intestine consists of an internal coat, the mucous membrane, and an external muscular coat. The peritoneum ensheathes the latter. Three bands of muscle run lengthwise down the large intestine and gather it into puckers, which give to this part of the alimentary canal a peculiar pouched appearance. The large intestine is about five feet long, and terminates in the rectum—a short straight portion of the gut which opens at the anus.

FIG. 114. The valve between the large and small intestine. *a.* Small intestine. *b.* Large intestine. *e, f.* Valve. *g.* Appendix.

The anus is guarded by a ring of muscle; this is under the influence of the nervous system, and controls the emptying of the bowels.

The mucous membrane here has no valvulae conniventes, villi, or Peyer's patches. It is lined with columnar epithelium, and contains simple tubular glands closely packed together like a set of test-tubes. The cells in these glands are distended with a mucous secretion. In the connective tissue between the glands lies a close network of capillaries, and here and there lymphoid nodules are to be found lying between the glands and the muscular coat.

Functions of the large intestine. Most of the material which is of any use to the body is absorbed in the small

intestine. The remainder passes through the ileo-caecal valve in a semi-fluid condition.

The function of the large intestine is to absorb what is left, and especially water. The contents of the large intestine, as they are driven on by peristalsis, become more and more solidified, and finally only the waste material is left which forms the faeces. Owing to fermentation produced by the growth of bacteria in this part of the intestine, the faeces acquire their peculiar odour and become acid.

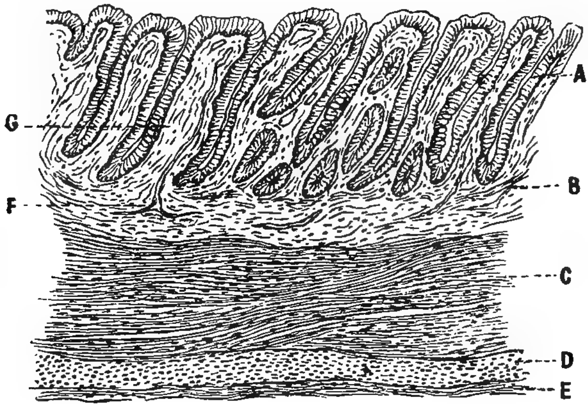


FIG. 115. Microscope, low power. Section through a fragment of the wall of the large intestine. A. Tubular glands of Lieberkühn lined with columnar cells. Many are mucous goblet-cells. C and D. Circular and longitudinal muscle. E. Peritoneum. G. Soft vascular connective tissue with B, muscle-fibres, and F, capillaries.

The faeces collect in a curved portion of the bowel just above the straight part or rectum, and there, exciting the nerves, set up uneasy sensations which lead to defaecation. To expel the faeces the breath is held, the circular sphincter muscle of the anus relaxed, and the abdominal contents squeezed by the contraction of the abdominal muscles. The walls of the rectum contract, and help to expel their contents.

Regular action of the bowels is of the utmost importance, for otherwise poisonous products are absorbed which arise

from bacterial fermentation of the faeces. The absorption of such leads to ill-health.

The natural purgative cellulose is to be obtained by eating fruit, brown bread containing the husks of wheat, and coarse oatmeal porridge for breakfast. A glass of cold water before breakfast is also of value. Constipation is usually a sign of general lack of tone, and shows that the body requires to be braced up by muscular exercise.

In cases of patients unable to take food by the mouth, it is possible to maintain life for some little time by injecting egg-white, starch solution, and meat-juice into the rectum. The columnar cells of the intestine digest and absorb a certain amount of albumin and starch, even though these substances have not been submitted to the action of the digestive juices.

In cases of cancer of the stomach, that organ has been more than once entirely removed by a surgeon, and the gullet joined to the duodenum. The greater part of the large intestine has also been taken away in disease, and the remainder joined to the anus. After both operations, the patients have recovered and digested their food, so it is clear that life is possible with a greatly diminished alimentary canal.

Hunger and thirst. Hunger is a sensation referred to the stomach, while the sensation of thirst is referred to the throat. A man may be hungry if his stomach be full of food and the passage into the intestine blocked so that absorption there is impossible.

This shows that it is not the emptiness of the stomach that causes the sensation of hunger.

The sensation is satisfied by the absorption of food. A person who is very hungry and bolts his food may eat far too much, for his appetite is not appeased until absorption begins. Starving people may thus kill themselves

by overloading the exhausted stomach. Alcohol, opium, and tobacco restrain the feeling of hunger. Many a poor man has breakfasted off a pipe. The danger of the alcohol and opium habits lies partly in the fact that hunger is abolished by these drugs, and thus insufficient food is taken. The sensation of hunger remains unnoticed in great states of mental excitement. Soldiers during a day's battle never remember the food in their knapsacks, and a person stricken with pain or grief refuses to touch food.

Too much salt in the food when absorbed occasions thirst by attracting fluid out of the tissues into the blood. The blood always tends to remain at a certain standard strength. If too much salt be absorbed from the intestine, water diffuses in from the tissues and dilutes the salt in the blood. After profuse sweating, the tissues contain less water, the body is drier, and thirst results. Thirst may be greatly relieved by a bath, or sponging the wrists with cold water, and by an acid drink such as lemon juice. Thirst can be relieved by injecting water into the rectum or under the skin as well as by drinking, for the water in each case rapidly enters the blood stream.

CHAPTER XXVI

THE LIVER AND THE DUCTLESS GLANDS.

The liver. The liver is a large and important organ, weighing about $3\frac{1}{2}$ lbs. Its upper convex surface fills up the dome of the diaphragm on the right side, and is thus protected by the lower part of the thoracic wall. With each inspiration the liver is pushed downwards and compressed by the diaphragm, and this rhythmic compression is of great importance, as it aids the flow of blood through the organ. Owing to vigorous respiration the circulation is quickened, and congestion of the liver prevented by muscular exercise. The liver extends from the right side of the abdomen across the middle line, and thus partly overlaps the stomach; when a person is standing upright the lower edge of the organ may be felt just below the thoracic cage. A doctor examines the edge of the liver here, to see whether it be congested and enlarged. Owing to tight lacing, the abdominal organs are displaced in many women, and the shape of the liver greatly distorted. The liver is covered with the peritoneum by which it is attached to the diaphragm and other structures. It is a very vascular organ, containing about one-fourth of the blood in the body, and distends or shrinks in size according to the quantity of blood within it. A fissure divides the liver into a right and left lobe, the former of which is much the larger.

On its under surface the right lobe is subdivided by fissures into three smaller lobes. Into one of these fissures pass the portal vein, the bile-duct, and a branch of the aorta called the hepatic artery. These three vessels dive into the substance of the organ and send branches to all its parts. Out of the liver at the posterior edge of its upper

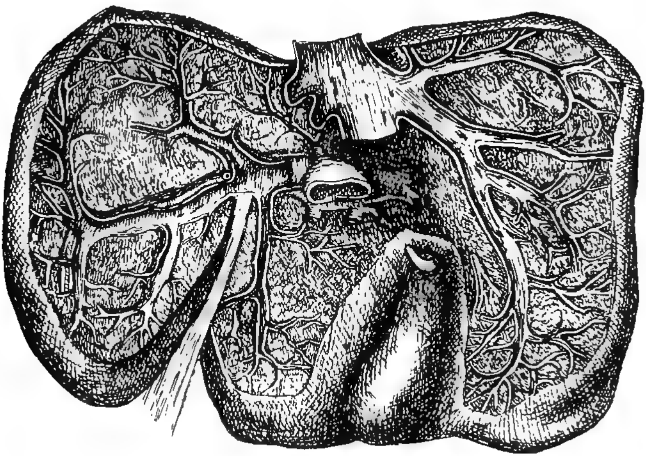


FIG. 116. Liver cut open to show on the left hand a branch of the portal vein bringing blood to the liver, on the right hand a branch of the hepatic vein collecting blood from the liver.

surface there issues a large vein, the hepatic vein, which opens immediately into the vena cava inferior at the point where the latter vessel pierces the diaphragm. The vena cava inferior, as it passes upwards, lies behind the liver in a sort of tunnel formed by a small lobe of that organ. This lobe rests against the vertebral column, and in such a way that the vena cava is protected from the weight of the liver. The hepatic artery is small in size, and brings far less blood to the liver than does the portal vein. The

function of this artery is to supply the tissues of the liver with oxygenated blood, while the portal vein conveys the venous blood from the intestines.

Examine the surface of a piece of liver obtained from the butcher, you will find it to be of a dark red colour and mottled over with little areas, each measuring about $\frac{1}{20}$th inch across. These are the lobules of the liver. The lobules are separated from each other by a few strands of connective tissue

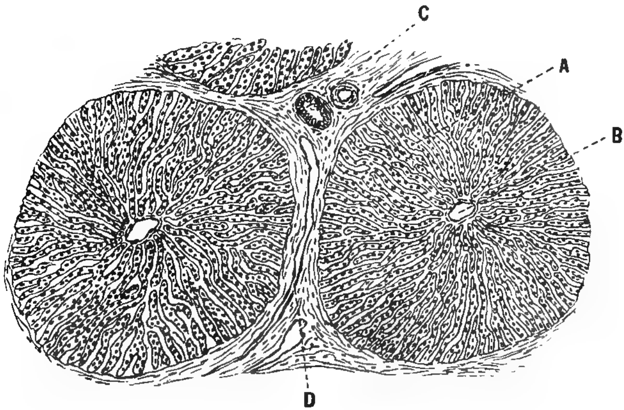


FIG. 117. Microscope, low power. Section through a fragment of the liver showing two lobules. A. Liver cells. B. Branch of hepatic vein. C. Branch of bile-duct. D. Branch of portal vein.

which support the finest branches of the portal vein, hepatic artery, and bile-duct. On cutting the liver, small gaping holes will be seen here and there. These are branches of the hepatic vein.

In principle, the structure of the liver is like that of any other racemose glands, but varies in certain details. In a racemose gland the duct branches into little ducts, and these finally terminate in sacs lined with secreting cells. The sacs are surrounded with capillaries. In the liver the lobules are not sacs, but solid masses of secreting cells,

and the bile-duct of each ends in minute channels which run between the cells. Through these channels the bile, which is secreted by the cells, percolates. In order to supply the little mass of cells with blood, the capillaries do not remain on the outside, but, running through the lobule, open into a vein lying in the centre. The central vein, on leaving the lobule, joins a branch of the hepatic vein. The blood is brought to the outside of the lobules by branches of the portal vein and hepatic arteries; it is the capillaries arising from these vessels which run in a network through the lobules, and end in the central veins. The latter carry the blood away to the hepatic vein, and thence to the vena cava inferior. The liver-cells which fill up the lobule lie in the meshes of the capillary network, and thus fall into groups which radiate from the outside of the lobule towards the central vein.

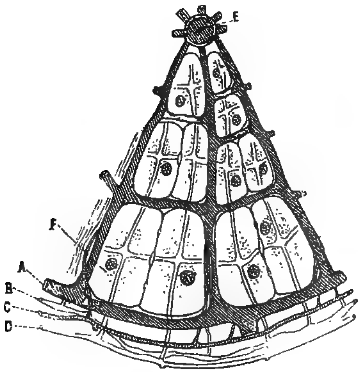


FIG. 118. Microscope, high power. Diagram of a portion of a lobule of the liver, showing the blood-vessels and bile-ducts injected with fluid. A. Branch of portal vein sending capillaries to open into E, a branch of the hepatic vein which lies in the middle of the lobule. B. A lymphatic. C. Branch of hepatic artery. D. Branch of bile-duct; into this open the ducts which lie between the liver-cells F.

Take a bag of lump sugar, and into the middle of it push a piece of stick. The bag represents a lobule of the liver. The lumps of sugar are the liver-cells, the stick the central vein. The crannies between the lumps are the channels through which the bile percolates. The bag is the connective tissue which surrounds the lobule.

Each liver-cell is five or six times as large as a red blood corpuscle, polygonal or many-sided in shape; it may contain granules, fat droplets, or lumps of a glassy looking substance called glycogen.

Functions of the liver. If a frog be taken when hibernating in the winter, and a fragment of its liver teased and examined under the microscope, the cells will be found swollen and full of glycogen. On adding a drop of iodine solution, the glycogen stains a reddish yellow colour. The liver-cells of a frog taken in the spring, on the other hand, are shrunk and contain granules, but no glycogen. The glycogen is a store substance set by for the winter needs of the frog. If a starving rabbit be taken and its liver examined, little glycogen will be found; on the other hand, the liver of a rabbit which has recently been fed on carrots will be full of glycogen. If two dogs be both given a meal, and one be kept quiet and the other be made to run after a cart all day, a great deal of glycogen will be found in the liver of the quiet dog, and very little in that of the other. Glycogen is a carbohydrate material resembling starch, which is stored in the liver when food is plentiful, and is used up during starvation and especially during muscular work.

Take out the liver of a rabbit immediately after its death. Chop it into pieces, and throw these into half a pint of boiling water acidulated with a teaspoonful of vinegar. This will coagulate the proteids. Smash up the liver in the water, and then filter the latter through a funnel of blotting-paper. Owing to the glycogen in solution, the water will now have a white opalescent appearance. When cold, test with iodine—a port-wine colour will result; this disappears on heating and comes back on cooling. It is the characteristic test for glycogen.

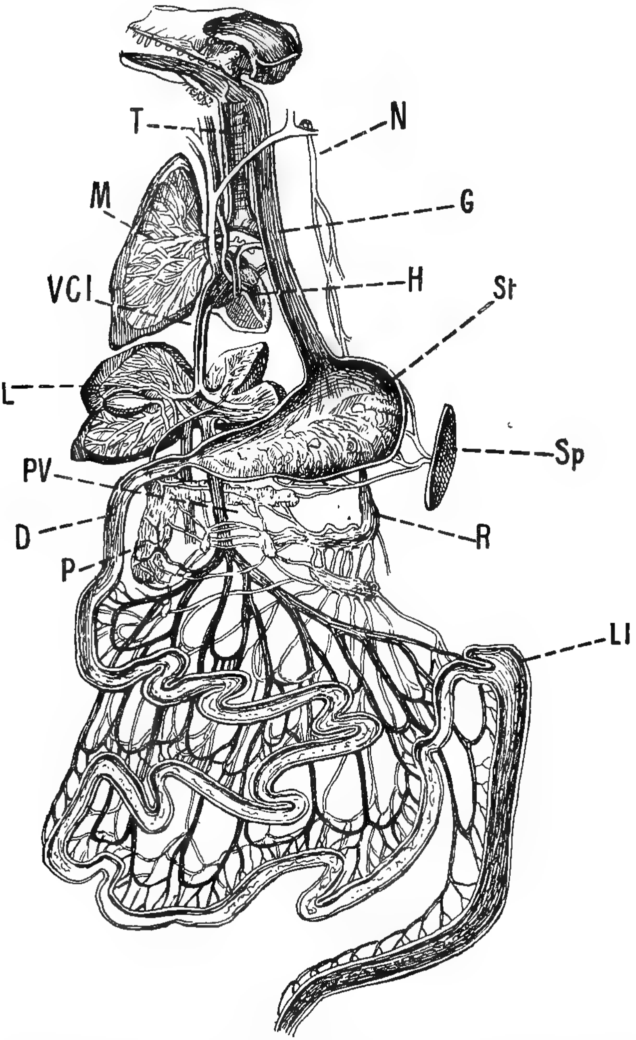


FIG. 119. Absorbent system of rabbit. D. Duodenum. G. Oesophagus. H. Heart. L. Liver. LI. Large intestine. M. Lung. N. Thoracic duct opening into subclavian vein in neck. P. Pancreas. PV. Portal vein. R. Receptaculum chyli. Sp. Spleen. St. Stomach. T. Trachea. VCI. Vena cava inferior.

If a piece of liver from the butcher be treated in the same way, no glycogen but grape-sugar will be obtained in the water. Test for sugar by boiling after the addition of caustic potash and copper sulphate. During the process of death the glycogen in the liver-cells is changed into sugar.

The sugar, absorbed by the small intestine, on reaching the liver through the portal vein is taken up by the cells, and turned into granules of glycogen. Only a very small amount of sugar is found in the arterial blood, say 1 ounce in every 1000 ounces of blood. If a little more than this quantity enter the blood, sugar passes out in the urine, and the functions of the body become disordered, for the excess of sugar acts as a poison. Such is the condition of affairs in the disease known as diabetes. The duty of the liver is to arrest the sugar brought by the portal vein during digestion, and turn it into glycogen. When food is required during times of hunger and hard work, the liver, by rendering up its glycogen, supplies food material to the tissues. It is generally supposed that the sugar in the blood is continually used up by the tissues, and that the glycogen stored in the liver is slowly changed back into sugar so as to keep the supply in the blood constant. Probably some of the glycogen is, by the action of the liver-cells, built into fat or compounded with the molecule of proteid, and thus the carbohydrate food may reach the tissues in quite a different form.

Glycogen is formed in greatest amount when an animal is fed chiefly on carbohydrates. It will, however, appear in the liver of a dog fed on lean meat and water only. Thus it is clear that the liver-cells can form the carbohydrate glycogen from the products of proteid digestion. Now

a carbohydrate contains only the elements carbon, hydrogen, and oxygen, and it may be asked, what happens to the element nitrogen, present in the amido-acids—those products of proteid digestion which are absorbed and carried to the liver, and from which the glycogen is manufactured. Urea is the chief nitrogenous waste product which results from the breaking down of proteid, and there is evidence to show that urea as well as glycogen is formed by the liver. An excess of proteid in the diet produces an increased excretion of urea in the urine; probably the excess, absorbed as amido-acids, is broken up in the liver into urea and glycogen, and, while the urea is excreted in the urine, the glycogen is either changed into fat, and stored up as such in the body, or else is used up in the production of muscular energy and excreted as carbon dioxide and water.

It is obvious from the above that excess of food coupled with deficient exercise will lead to the choking of the liver-cells with food products which are not required. If the liver be thus congested it must be relieved first by a purge, and then by a spare diet and exercise. The nature of the secretion of the liver—the bile—has already been partly dealt with in the last chapter.

The bile is an alkaline fluid, and contains bile-salts, pigment, cholesterin, lecithin, and inorganic salts. It is important both as a digestive fluid aiding the absorption of fat and as an excretion. The bile pigment is a waste product of the red blood corpuscles. Gall stones are produced by inflammation of the gall-bladder changing the bile and causing cholesterin to become insoluble. The stones may block up the bile-duct and produce great trouble and pain. The bile-salts, compounded of complex organic substances, are not excreted in the faeces like the pigment and cholesterin, but are reabsorbed from the intestine. About two pints of bile are excreted by the liver each day. The secretion is a continuous one. During hunger the orifice

of the bile-duct, into the duodenum is closed, and the bile passes up a side-tube into the gall-bladder, and collects there. Whenever acid chyme passes over the orifice of the duct, the gall-bladder empties some of the bile into the intestine. The liver has then many important functions. It excretes bile, stores up glycogen, forms fat, manufactures urea, and generally controls the composition of the blood.

Ductless Glands.

The Spleen. The spleen is situated in the abdomen on the left side, and just behind the stomach. It is about five inches long, is thin, and flattened in shape.

The spleen or milt of an ox may be obtained from the butcher. On cutting the spleen open it will appear of a purplish red colour, and feel soft and pulpy. Small white spots will be seen scattered in the pulp. The organ is covered with a capsule consisting of fibrous and elastic tissue and spindle-shaped muscle-cells. If a slice of the spleen be held under a water-tap, most of the pulp will be washed out, and a meshwork of connective tissue will come into view. The spleen, then, is composed of a framework of fibrous, elastic, and muscular tissue, the meshes of which are filled with pulp, and the whole surrounded by a capsule.

The pulp is formed of red and white blood corpuscles and lymph-cells, the latter of various shapes and sizes. The cells are supported by a fine network of connective tissue. An artery supplies the spleen with blood from the aorta. The branches of this artery open into the splenic pulp, and the blood filtering through this is then gathered up by veins and returned to the portal vein. It is a peculiar feature in the structure of the spleen that the blood does not circulate through capillaries, but actually percolates through the pulp. The small white

spots scattered about the pulp are formed of lymph-cells densely crowded together into little masses or nodules. The masses are situated on the branches of the splenic artery.

Functions of the spleen. The spleen is a large organ, and yet it has been completely removed from man and from animals without any apparent effect. It probably helps to control the composition of the blood. White corpuscles are formed and added to the blood by the multiplication of the lymph-cells in the spleen, and possibly new red corpuscles are also produced there. When the spleen is removed, these functions can still be carried out by the lymph-glands and the red marrow of the bone.

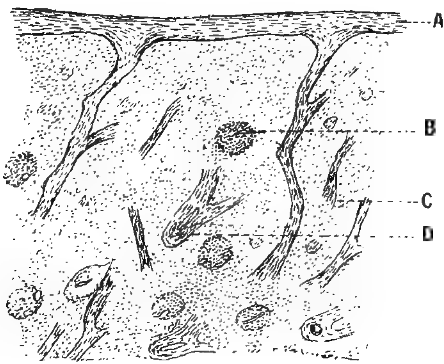


FIG. 120. Microscope, low power. Section through a fragment of the spleen. A. Fibrous and muscular coat from which partitions run into the substance of the gland and thus support C, the splenic pulp. B. Dense groups of lymph-cells. Blood-vessels run in the fibrous partitions D. and end in the pulp.

The spleen is remarkable for undergoing rhythmic expansion and contraction. The change in volume is brought about by the muscular tissue in the spleen. At each expansion the spleen becomes filled with blood, and by pumping the blood on into the portal vein the spleen, at each contraction, promotes the flow of blood to the liver. The pumping action of the spleen occurs regularly once in

every minute or two, and is especially vigorous during the digestion of food.

The thyroid gland. This gland is situated in the neck. It consists of two small lobes lying on each side of the trachea and joined together by a narrow piece which crosses the trachea. The gland is surrounded by a capsule of connective tissue, and consists of a number of minute sacs; each sac is lined with a layer of cells and filled with

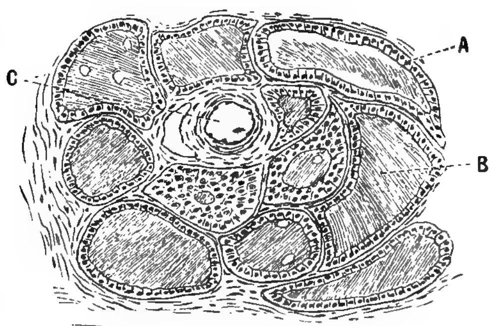


FIG. 121. Microscope, low power. Section through a fragment of the thyroid gland. A. Cells lining the alveoli. B. Glassy-looking secretion. C. Blood-vessel.

a glassy-looking substance. This is a peculiar form of proteid secretion, and contains iodine in addition to the usual elements found in proteids. The gland is exceedingly vascular, and interchange takes place between the blood and lymph and the glassy material. There are in contact with the thyroid, or buried in its substance, some little distinct masses of gland cells called *parathyroids.* Some hold that these are similar to the thyroid and can develop into a structure like it. Others think they are distinct glands and very necessary to life. If the thyroid gland atrophy in a child, a condition of idiocy is produced, and the child grows up

a *cretin*. Bodily and mental growth is arrested, and a cretin aged twenty may remain the size of a child, and like to play with dolls. If a cretin be fed on thyroid glands taken from sheep his condition is improved, while if a normal man be fed on thyroids, he becomes thin and exhausted. It is clear then that the thyroid gland produces a material necessary for the growth of the body, and that enough of this material and not too much is required to keep the body in health.

The supra-renal capsules. These are two little glands situated in the abdomen. One rests on the top of each kidney. They are in shape something like a cocked hat. On microscopical examination each supra-renal is found to be formed of columns of cells radiating from the outside to the middle of the gland. The middle of the gland or medulla is different in origin and structure to the outer part or cortex, and is developed from a part of the sympathetic system—a ganglion turned gland so to speak. The cells are supported by a framework of connective tissue, and are supplied with a network of capillaries.

If both supra-renal glands be removed from an animal, death takes place in a few days' time. When these glands become diseased in man, death occurs from gradual and advancing exhaustion. At the same time the man's skin may become coloured brown.

An extract of the medulla of fresh supra-renal glands, when applied to a wound, causes a remarkable constriction of the blood-vessels and stops bleeding. It is thought that the medulla of these glands has to do with keeping up the vigour of the sympathetic system of nerves by secreting a substance which enters the blood and acts particularly on these nerves. The cortex has something to do with the growth of the body and the development of puberty. It is a very remarkable fact that the presence of such little glands as the supra-renals should be absolutely essential to the existence of the whole body.

CHAPTER XXVII

THE KIDNEYS AND THE EXCRETION OF URINE.

In the previous chapters the digestion and absorption of food has been traced, and the intaking of oxygen and the excretion of one of the great waste products—carbon dioxide—described. There still remain to be discussed those mechanisms of excretion by which the other waste products of the tissues, namely, urea, mineral salts, and water are removed from the blood and cast out from the body.

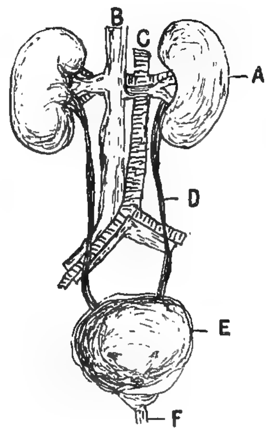


FIG. 122. Diagram to show A, kidneys. B. Vena cava inferior receiving renal veins. C. Aorta giving off renal arteries to kidneys. D. Ureters. E. Bladder. F. Urethra which opens externally.

The kidneys. The kidneys lie one on each side of the vertebral column in the lumbar region. They are dark red organs about four inches long and two broad, and of the shape of a kidney bean.

A sheep's kidney can be obtained from the butcher for examination; it closely resembles the same organ in man.

In the carcase of a sheep at the butcher's shop you may see where the kidneys lie more or less embedded in fat and attached to the back wall of the abdomen. Each kidney receives a large artery from the aorta and gives off a large vein which enters the vena cava inferior. While the outer edge of the kidney is convex, the inner edge and the one turned towards the vertebral column is concave; into this concavity or *hilus* the vessels dive and so reach the substance of the organ. Beside the artery and vein there issues from each kidney a white tube, the *ureter*. The two ureters run down the back wall of the abdomen and open into the bladder, which is a receptacle for the urine lying in the pelvic basin.

The bladder. The bladder is a muscular bag lined on the inside with mucous membrane. The ureters pierce the wall of the bladder obliquely. Their orifices are thus covered by a flap of mucous membrane which prevents the urine passing back into the ureter. The urine continually drops from the ureters into the bladder, and when a certain amount has collected, a feeling of uneasiness arises, owing to the distension of the bladder. When the bladder of an adult is moderately full, it is shaped like a flask and holds about a pint. Beneath the pubes the neck of the bladder opens into the *urethra*. This is the passage leading to the exterior. Around the neck of the bladder there are gathered some bands of muscle-fibres which act as a sphincter and keep the orifice closed. When the bladder is distended, it strives to contract and expel the urine, but the act of expulsion can be prevented by the closure of the sphincter muscle. The mechanism of expulsion is under control of the nervous system. The sensory nerves in the wall of the bladder are excited by the distension of the latter. The irritation spreads up these nerves to the spinal cord, and there

provokes the despatch of impulses down the nerves which supply the muscular wall of the bladder and the sphincter. The muscular wall is commanded to contract, the sphincter to dilate. At the same time, however, the sensations pass up to higher nerve-centres situated in the brain, and the brain may, either by countermanding the order of the spinal cord, keep the sphincter contracted, or else, when the occasion is fitting, allow the expulsion of urine to take place. Suppose the spinal cord be divided from the brain in the thoracic region; as a result of such an injury the patient will lose all control over the sphincters of his bladder and anus. Both the urine and faeces will be then passed involuntarily.

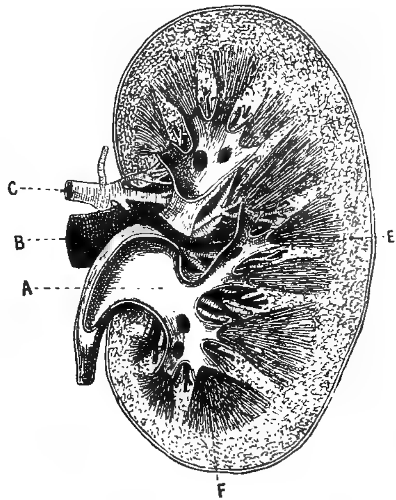


FIG. 123. The kidney divided crosswise. A. The dilated end of the ureter. The pyramids F project into this. B. Renal vein. C. Renal artery. E. Cortex of the kidney. After Testut.

In young children the power of control over the sphincter is much less, and the bladder more irritable when distended. Children should not be severely punished for being unable to retain the urine during the night, as this is simply a symptom of deficient nervous control; frightening a child may increase the nervous instability instead of remedying it. Many children fall into the habit of not completely emptying the bladder at bedtime, and attention should be directed to this point.

Examination of the sheep's kidney. With scissors slit open the ureter, and trace it to where it dilates into a funnel-shaped bag—the *pelvis* of the kidney. The pelvis and the ureter are lined with a whitish mucous membrane. Projecting into the pelvis there are several conical processes of pale kidney substance. These are the pyramids of the kidney. Each consists of a number of minute tubules, which open into the pelvis. On squeezing a pyramid a drop of urine may exude from the tubules.

Cut open the kidney with a knife, passing the knife through the organ from the pelvis to the convex border. The pyramids will now be fully exposed; while their points project into the pelvis, their bases stretch out into the substance of the kidney. There are in all about twelve pyramids, and these occupy the central portion of the kidney or *medulla*. On the outside of the medulla lies the *cortex* of the kidney; this is dark brown in colour and of a more granular texture. In comparison with the cortex the medulla appears pale in colour and streaked. Running between the pyramids there may be seen here and there blood-vessels laid open by the knife.

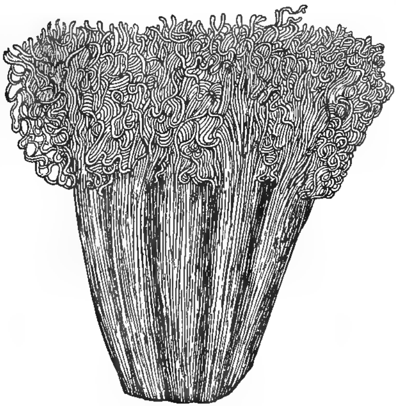


FIG. 124. Microscope, low power. The tubules of one of the pyramids of the kidney partly unravelled. The tubules are convoluted in the cortical part and straight in the medullary part of the kidney.

Such is the structure of the kidney as revealed by the naked eye. Unravelled with the aid of the microscope, the substance of the kidney is found to be composed of multitudes of long and coiling tubules lined with secreting cells. The tubules are held together by connective tissue and are surrounded by a meshwork of capillaries.

Each secreting tubule has a long and convoluted course. It commences in a *capsule* which encloses a little round body, the *glomerulus*; this is situated in the cortex. The glomerulus is formed of a cluster of capillaries closely coiled together; the cluster projects into the capsule of the tubule. Between the blood in the capillaries and the inside of the capsule there are two layers of thin flat cells, namely, the cells of the capillary wall, and the cells of the wall of the capsule. Take a glove and push your finger into the top of one of the finger-stalls, this will give you an idea of how the cluster of capillaries in a glomerulus pushes in the thin dilated extremity of a tubule and so comes to hang within it.

The tubule, on passing from the capsule, first coils about in the cortex, and then running down into the medulla forms a loop there. Looping back to the cortex the tubule once more coils about; finally, it joins a collecting tubule which runs straight through a pyramid and carries the secretion down to the pelvis. It is only in the capsule that the tubule is lined with thin flat cells, in the rest of its course the cells are of a cubical shape and resemble those found in other secreting glands. The tubules of the kidney are exceedingly fine thread-like structures not more than $\frac{1}{500}$th of an inch in diameter, and thus there are thousands upon thousands of them packed together in each kidney. When the cortex of the kidney is cut open it appears granular to the naked eye because of the glomeruli and the convolutions of the tubules there; in the pyramids the tubules run straight down either to form loops or to open into the pelvis, and thus this part has a more striated appearance.

Circulation in the kidney. Diving into the substance of the organ the renal artery breaks up into branches which run between the pyramids. Arriving at the junc-

tion of the medulla with the cortex these branches form arches in the substance of the kidney. From the arches, small arteries run outwards into the cortex to supply the glomeruli, inwards, to supply the pyramids. Each glomerulus is supplied by its own little artery and vein. The

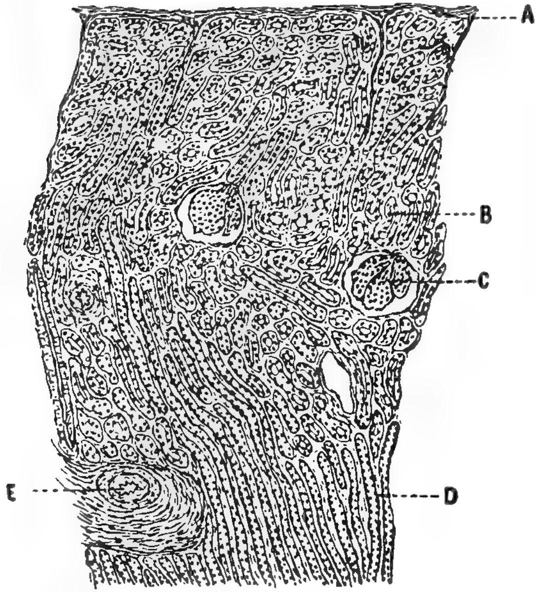


FIG. 125. Microscope, low power. Section through a fragment of the kidney. A. Connective-tissue coat or capsule. B. Convoluted tubules. C. Glomerulus. D. Loops and collecting tubules. E. Artery.

latter, on issuing from the capillaries of the glomerulus, breaks up into a second set of capillaries round the convoluted tubules. The blood is finally gathered, both from these and from the capillaries in the pyramids, by veins which join together to form the renal vein. In the above account the following peculiarities of structure should be particularly noticed:—

(1) The arterial blood in the glomerular capillaries is separated from the inside of the capsules by thin flat cells only.

(2) The convoluted tubules are supplied by blood which has first already passed through the glomeruli. Thus the blood passes through a double set of capillaries; firstly, in the glomeruli, secondly, round the convoluted tubules. The latter are lined with secreting cells.

(3) The veins which leave the glomeruli are said to be smaller in size than the arteries which enter them.

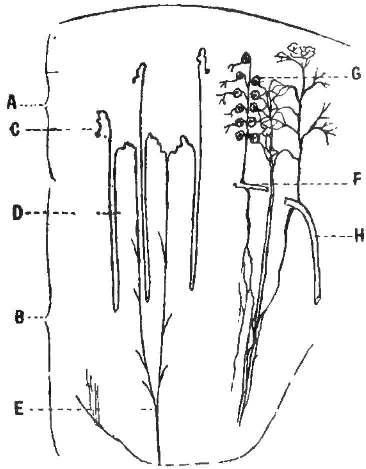


FIG. 126. Diagram showing the course of the tubules and blood-vessels of the kidney. A. The cortex. B. The medulla. C. Capsule. D. Loop. E. Collecting tubule opening into the pelvis. F. Branch of artery. G. Glomerulus of capillaries which hangs in each capsule. The vein coming out of each glomerulus breaks up into capillaries round the tubules. H. Vein collecting the blood from the capillaries.

It is thought probable that most of the water passes through in the glomeruli, while the urea and other substances in the urine, and some of the water, are secreted by the secreting cells which line the convoluted tubules. The secretion depends on the activity of the living cells; these withhold certain substances in the blood, others they allow to pass. Both sugar and urea when in solution are diffusible substances, that is to say, they easily pass through the

pores of a dead animal membrane. Traces of both exist in the blood, but by the healthy kidney-cells urea alone is taken. There are not more than two parts of urea by weight in every ten thousand parts of blood, while in urine there are two parts of urea in every hundred parts of water. It is the cells of the renal tubules that produce the more concentrated solution out of the less concentrated. If we separate two solutions of urea by a dead animal membrane, the urea will pass from the more to the less concentrated. The reverse process cannot be imitated. It is not carried out by filtration or diffusion, but by the living activity of renal protoplasm. If the cells of the tubules be damaged by an impeded circulation of the blood or by some poison, they no longer control the secretion. In Bright's disease not only albumin, but even blood, may appear in the urine; similarly, in jaundice there is excreted bile, and in diabetes, sugar.

The secretion of the urine is modified in the healthy animal, firstly, by influences which affect the amount of blood flowing through the kidneys; secondly, by substances which, when absorbed in the blood, excite the cells of the tubules to secrete. The renal artery is very large, and the blood flows through with great rapidity. In winter, the cold causes the vessels of the skin to contract. The vaso-motor nerves bring about this change in order to diminish the loss of heat. It follows that the blood driven from the surface must circulate in greater volume through the viscera. The kidneys react to the increased blood supply, and in consequence secrete more water. In summer, the conditions are just the opposite; the sweat-glands in the skin obtain an abundant supply of blood, the kidneys less, more water passes away in the sweat, and thus the urine becomes concentrated. The drinking of fluid in large quantities increases the volume of the

blood, and makes it dilute. The kidneys are in consequence excited to greater activity, and the blood is rapidly restored to its proper strength by the copious excretion of dilute urine. The presence of urea in the blood naturally excites the renal cells to secrete. Certain salts, such as nitrate of potassium or sodium, are used as drugs to promote the flow of urine. Other drugs, which act on the heart and blood-vessels, increase or diminish the excretion of urine by rendering the circulation through the kidney more or less active. In heart disease, when the heart fails to pump efficiently, the blood stagnates in the veins, and the circulation through the kidney becomes deficient. Water then passes out of the capillaries into the interstices of the tissues, producing dropsy. In such conditions, digitalis, a powerful drug extracted from foxglove leaves, is largely used. Digitalis increases the power of the heart muscle, braces up the circulation, and, by promoting the excretion of urine, removes the dropsy.

Composition of urine. Urine is an amber-coloured fluid, clear and transparent when passed, and slightly acid in reaction. It contains organic substances and mineral salts in solutions, and is therefore a denser fluid than water. The density or specific gravity of the urine is determined by observing how deeply the stem of a hydrometer sinks in it. If the specific gravity of water be called 1000, then that of normal urine is about 1020. The specific gravity is a simple indication of the amount of solids in solution in any sample of urine. In diabetes, the specific gravity will be too high, because sugar is excreted in the urine. While after copious drinking the specific gravity is low, it will be high after profuse sweating. In the first case, the proportion of water to solids is increased, and in the second case, diminished. The quantity of urine passed by a man is about

two or three pints a day. The quantity varies with the amount of drink taken, and with the amount of perspiration lost. If more water is lost from the skin, less is passed out in the urine. While the quantity of water varies, the amount of solid matter excreted in the urine remains about the same each day.

The chief organic substance in the urine is urea. If the urine passed during one day be collected and evaporated, about one and a quarter ounces of urea can be separated off from the solid residue. The chief mineral salt which will be left, after the separation of the urea, is chloride of sodium, and in smaller amounts sulphate and phosphate of sodium, with similar salts of potassium, calcium and magnesium. Almost one ounce of these mineral salts is passed in the day.

Besides urea, there are traces of other nitrogenous substances in the urine, such as ammonia and *uric acid.* Uric acid combines with sodium, potassium, and ammonium to form urates, and these are more soluble in warm than in cold urine. Hence a precipitate of urates, coloured brick-red by a pigment which exists in the urine, may fall down when the latter is left to stand in a vessel. This precipitate will dissolve again if the urine be warmed. Uric acid is a less oxidised waste product of proteid than urea. In birds and reptiles, uric acid takes the place of urea and forms the chief nitrogenous waste product. In man, the quantity of uric acid is increased by eating sweatbread, liver, and kidney; in gouty conditions, uric acid may collect in the fibrous tissue round the joints. There is no real evidence that an excess of uric acid in the blood is the cause of gout or that such an excess does any harm, although quack advertisements constantly say the contrary.

Stones in the kidney or in the bladder are formed by the crystallisation of uric acid, urates, or other mineral salts out of the urine. Gravel in the urine is due to the crystallisation of uric acid from a want of alkali to keep the uric

acid dissolved. By the organic acids and salts in green vegetables and fruits, the alkalinity of the urine is increased, and the uric acid rendered soluble. Stones, when once formed in the kidney or bladder, lead to great suffering, and can only be removed by the surgeon.

The amount of urea in the urine varies with the amount of proteid in the diet. A starving man excretes about five grammes of nitrogen every day, owing to the waste of his tissues; this amount must be more than fully replaced by proteid food. If more proteid food than is required to repair the tissues be absorbed, it is broken down in the liver into glycogen and urea, and the latter appears in the urine, while the former either undergoes combustion in the tissues, and is excreted as carbon dioxide and water, or is turned into fat, and stored away in the tissues as such.

The kidneys do not manufacture urea, for this substance continues to collect in the blood after removal of both kidneys, and finally poisons the system. Since the muscles form the flesh of an animal, and contain most of the protoplasm that exists in the body, we might expect to find urea in them, for this is the nitrogenous waste product of living protoplasm. Only a very little urea, however, is to be found in the muscles. The only organ that we know to possess the power of forming urea is the liver. If the blood of a well-fed animal be circulated artificially through the vessels of an excised liver, and the urea be estimated in the blood before it enters the liver and after it issues from it, a decided increase in the amount will be obtained. Similarly, if certain salts of ammonia are circulated through the liver, these are changed into urea. Moreover, destruction or acute disease of the liver leads to the appearance of ammonia in the urine in place of urea. Taking into account these facts, it seems probable that the muscles and other protoplasmic tissues give off ammonia salts to

the blood, which are changed by the liver into urea and excreted as such by the kidneys.

The kidneys, besides excreting the urine, like most of the other glands, exert some important influence on the body generally. A small piece of one kidney, if all the rest be removed, is able to excrete the full, and more than the full quantity of urine. In chronic Bright's disease, when the kidney substance is gradually destroyed, the sufferer produces and excretes more (not less) urea and water than he ought to do. Thus his tissues tend to break down too fast, and waste away. In some mysterious and as yet unexplained way, the kidneys control the waste of the tissues. Similarly the pancreas, besides secreting pancreatic juice, controls waste, for, if this organ be removed, diabetes results, sugar is lost in the urine and the animal dies. The liver, the kidneys, the pancreas, the thyroid, and the supra-renal glands draw substances out of the blood and return products to it. The waste product of one organ may be the food products of the others, and it is only by such give and take that the whole body can be preserved in health.

Collect all the urine passed during 24 hours. Measure the quantity. With a hydrometer determine the density of the urine. Test with litmus-paper, it is acid. Evaporate a little urine in a dish to dryness, and observe the solid residue = urea and salts. Evaporate some more urine to one-fourth of its bulk, add a few drops of nitric acid, and examine a drop of the mixture microscopically. You will see crystals of urea nitrate.

Add fuming nitric acid to urine in a test-tube. Gas will come off, for the urea is broken down into nitrogen, carbon dioxide, and water.

Add a little hydrochloric acid to urine in a glass, and let it stand. Next day there will be a little pink deposit of uric acid at the bottom of the glass. Healthy acid urine is not changed by boiling, for there is no albumin in it. On boiling urine after the addition of caustic potash and copper sulphate, no red precipitate occurs, for no sugar is present in healthy urine.

CHAPTER XXVIII

THE SKIN, THE EXCRETION OF SWEAT, AND THE REGULATION OF ANIMAL HEAT.

The epidermis and dermis. The skin consists of two coats, the *epidermis* and the *dermis.* The epidermis is composed of several layers of cells, the outermost of which are horny in nature. The dermis is the inner coat, and supports the epidermis. It is composed of a tough felt-work of fibrous and elastic tissue. Beneath the dermis, there lies a layer of subcutaneous fat which gives roundness and softness to the outline of the figure. Underneath the fat lie the muscles ensheathed in membranes of connective tissue. To these membranes, and to the superficial prominences of the bones, the dermis is bound by loose bridles of connective tissue. The skin can thus be pinched up and moved about over the deeper structures. The healthy skin when grasped is firm and elastic, not soft and flabby. You have already learnt how important is the condition of the skin in regard to the support of the veins and the maintenance of the blood-flow therein. The skin protects the soft tissues beneath from injury, and at the same time binds them into their proper places. The subcutaneous fat acts as a buffer against the pressure of surrounding objects, affording a soft cushion to the body.

If a fragment of the horny layer taken from the palm of the hand be teased up on a glass slide and examined under the microscope, it will be found to consist of flat, horny, and scale-like cells.

These, as they are worn off, are renewed by deeper layers of soft growing protoplasmic cells. The fibrous coat, or dermis, rises up into the epidermis so as to form

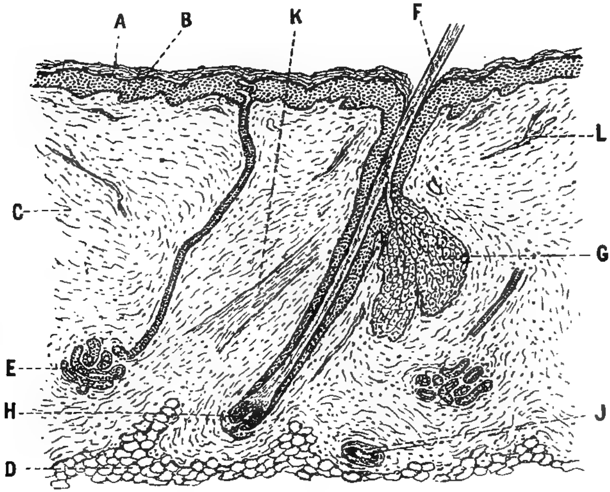


FIG. 127. Microscope, low power. Section through the skin. A. Horny layer of cells. B. Layers of soft growing cells. C. Thick connective-tissue coat D. Fat layer. E. Sweat-gland and duct. F. Hair. G. Sebaceous gland. H. Papilla of hair. J. Small artery. K. Muscle of hair. L. Capillaries.

little folds or papillae. The papillae are covered and the depressions between them filled with the layers of soft growing cells. The deepest cells, those next the dermis, are columnar in shape. The columnar cells, by constantly dividing and producing new cells, push up those above them. The outermost layers, as they become pushed further from the blood supply, turn dry and horny, and are squeezed into flat scales. The soft growing cells are

known as the Malpighian layer of the epidermis, and it is there that granules of pigment collect in the coloured races. The healthy cells on dividing never grow inwards towards the dermis, but only outwards. Each tissue keeps its own place and resists the invasion of other tissues around it. When the cells of one tissue or organ invade another, and by their overgrowth destroy that, a tumour or cancer is produced. The causation of such cancerous growths is as yet unknown. One set of cells must, by some means, be excited to unbridled growth, while the resistance of the other tissues to the invasion must, at the same time, be lowered.

In places where wear and tear is considerable, as in the palms of the hand and the soles of the feet, the horny or *corneous* layer becomes greatly thickened. There are no blood-vessels in the epidermis; the dermis, on the other hand, is extremely vascular. The larger vessels of the dermis lie more deeply, while the fine networks of capillaries run into the papillae. From these capillaries, lymph exudes, and nourishes the soft growing cells of the epidermis. On applying an irritant to the skin, or after a burn, the lymph exudes from the damaged capillaries in a large amount, and, by raising up the horny layer, forms a blister. The rashes of fevers are produced by spots of inflammation where the blood-vessels are congested. Situated in the papillae are little round or oval structures, called touch-corpuscles. Nerve-fibrils end both in these and among the cells of the epidermis: it is by their means that we estimate the pressure and size of objects, and whether they be rough or smooth, sharp or blunt, warm or cold.

On the back and shoulders the dermis is very thick and contains few touch-corpuscles. It is thus suited for the carrying of heavy burdens. The skin of the face and fingers is thin, and the dermis there is very vascular and crowded with touch-corpuscles. These parts are exposed to the cold and so require an ample blood supply. It is here

that we have the most delicate tactile perception of external objects.

The skin is thrown into ridges and creases. On the balls of the fingers these ridges run in concentric lines forming remarkable whorl-like patterns. In no two men are these patterns exactly similar; thus, by taking wax impressions of their finger-tips, criminals can be identified at any subsequent period. This is rendered possible by the fact that the ridges never change during growth, but retain the same pattern from birth to death.

The skin contains certain appendages, sweat-glands, hairs, and sebaceous glands. The sebaceous glands are attached to the hairs, and secrete a fatty material which keeps the skin and hairs greased. In water-birds like the duck this grease is important, as it prevents the feathers becoming soaked with water.

Sweat-glands. If the skin of the palm be examined with a lens, minute pits may be seen, set in rows on the ridges. These pits are the pores, or ducts, of the sweat-glands. Each gland is composed of a little tube, which is coiled into a knot, and ends blindly. The coiled tube is lined with secreting epithelium, and surrounded with a network of capillaries. The sweat-glands rest on the pad of fat just beneath, or in the deepest layer of the dermis. The duct of each rises up through the dermis, and, piercing the epidermis in corkscrew fashion, opens on the surface. It has been estimated that there are in every square inch of the palm of the hand some 3000 sweat-glands, while on the back and neck the number is much less, namely, about 400 in each square inch. The skin of the whole body is provided with at least two million sweat-glands. The length of each tube is about a quarter of an inch, and, from these figures, it is calculated that a man possesses about ten miles of sweat-tubes.

The sweat. The sweat is a watery alkaline and salt fluid. It contains only traces of organic and mineral substances, and common salt is the most abundant of these. The secretion of the sebaceous glands is mixed with the sweat, and, owing to the presence of fatty acids in this, the reaction of the skin is rendered acid. Some carbon dioxide gas is dissolved and excreted in the sweat. The same gas is present in the urine, bile, saliva, and other fluids of the body. Perhaps $\frac{1}{50}$th part of the carbon dioxide excreted each day is thrown off by the skin. In frogs, the respiratory function of the skin is far more important; these animals, after removal of the lungs, are maintained alive by the action of the skin. Both oxygen and water are absorbed by the frog's skin, while carbon dioxide is excreted. The absorbing power of a man's skin is very slight, as can be seen by the fact that we can handle poisons with impunity. This is owing to the horny layer, for poisons applied to a wound or blister or injected into the dermis are rapidly absorbed. The sweat is secreted continuously, but as a rule in such small quantity that it evaporates from the pores into the air as fast as it is formed. This is called *insensible perspiration,* for we are not conscious of the secretion taking place. Nevertheless about a pint of sweat is thus lost in the course of the day. In hot weather, or during exercise, the perspiration is poured out faster than it can evaporate. It collects in drops, and runs down our faces, and bedews our bodies. This is called *sensible perspiration.*

The evaporation of the sweat. The evaporation of water cools the body, for, as you have learnt in Chap. VI, a great deal of heat is rendered hidden or latent when a liquid is changed into the state of vapour. The most important function of the sweat is to control the loss of heat from the body. On hot days, or when more heat is produced by the

increased combustion which takes place in the muscles during exercise, the skin is flushed with blood, and the sweat poured forth in quantity. Heat passes off from the blood in the vessels by radiation and convection, and is, at the same time, carried away as latent heat by the evaporation of the sweat. On cold days, the vessels of the skin are constricted, and the sweat is secreted in small amounts. The danger on a cold day of becoming wet through or sleeping in damp places is apparent, for the evaporation of the moisture robs the body of its heat. So long as the body is warm, damp can do no harm, for it is not the moisture, but the lowering of the temperature of the body, that is dangerous.

The amount of blood in the skin is controlled by the vaso-motor nerves; the secretion of sweat is controlled by sweat-nerves. As a rule, the former nerves dilate the blood-vessels at the same time as the latter excite the sweat-glands to secrete. The nerve-centres which control the vaso-motor and sweat-nerves of the skin are set in action by sensations of heat and cold, or by changes in the quality and temperature of the blood. In 'cold sweats' the two sets of nerves act in the opposite way; the glands secrete during a paroxysm of fear, and beads of sweat gather on the face, but the vessels are constricted, and the skin pale and cold.

Sweat-nerves. That a warm atmosphere evokes sweating by means of the nerves is shown by the following:—

A cat sweats from the balls of its feet where the fur is absent. If the nerve of the leg of a cat be severed and the animal be placed in a Turkish bath, the pad of the foot on that leg will not sweat, while the other three feet will. The sweat nerves run in the sympathetic system.

A dog has no sweat-glands, but cools himself by opening his mouth and lolling out his tongue. Water

evaporates from these parts and not from the skin. It is therefore cruel to muzzle up *tightly* the mouth of a dog.

In birds there are no sweat-glands, but water evaporates from the surface of the membranous air-sacs. These lie within the body, and are in connection with the lungs and windpipe.

Effect of varnishing the skin. Varnishing the whole skin or coating it with oil leads to the death of animals whose bodies are clothed with hair or fur. They die from loss of heat, for the varnish destroys the non-conducting power of the fur. There is a pathetic story told of a child who was gilded to represent an angel in a pageant held in honour of one of the Popes. The death of the child took place in a few hours, and was probably due to some poison absorbed in the process of gilding, for it has been recently proved that a man, in contra-distinction to an animal, can live after his body has been covered with a layer of impenetrable substance. To make up for the absence of a furry coat there is developed in man a most perfect mechanism for controlling the loss of heat, and thus he remains unharmed by a coat of varnish.

Cleanliness. By washing, the skin is cleansed of bacteria and parasites, and the sweat-pores freed from clogging dirt. Cold baths stimulate the nervous system and invigorate the circulation. A cold bath every morning is one of the best of tonics. In trades where white lead or other poisons are handled, cleanliness becomes of the utmost importance; the eating of food with begrimed hands must be particularly avoided. Poisons such as white lead, arsenic, phosphorus, or mercury lead to terrible mischief when slowly absorbed day by day in small doses. Similarly the continual breathing of fine

mineral dust, as in metal-grinding, drilling in mines, and stonemason trades, leads to damage of the lungs, while the irritation of the skin by soot or tar has been known to produce particular forms of cancer in chimney-sweeps and tar-workers respectively. In all such trades the bodies of the workers should be kept clean, the air of the factories swept free of impurities by good ventilation, and mineral dust kept down by water sprays.

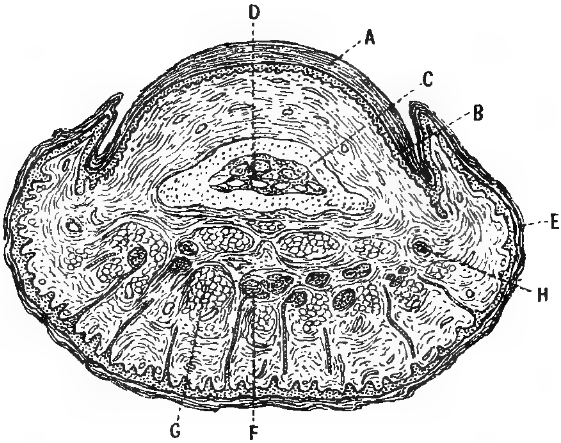


FIG. 128. Microscope, low power. Section through tip of finger. A. Nail. B. Groove at edge of nail. C. Bone. D. Marrow. E. Epidermis. F. Sweat-gland. G. Fat-cells. H. Blood-vessel. Fibrous connective tissue supports these structures.

The nails. The nails are modified parts of the skin. The horny layer of the epidermis is greatly thickened in the nail, for the deeper layer of cells resting on the dermis, by growing and multiplying, adds to the thickness of the nail, and at the same time pushes it forwards. The dermis on which the nail rests is called the *nail bed.* It is thrown into ridges bearing papillae and is extremely vascular. This part, being provided with nerves, is very sensitive and forms the 'quick of the nail.'

Hairs. During the growth of the child the hairs are developed in the following way. The epidermis here and there grows down into the dermis, and forms a little solid mass of cells, called the *hair follicle.* Into the bottom of the hair follicle the fibrous tissue of the dermis rises up to form a vascular papilla. The sides of the follicle are at the same time surrounded with a thickened layer of fibrous tissue. The cells on the top of the vascular papilla next begin to multiply, and by pushing and squeezing those above them, form in the follicle an inner solid core or rod of flattened scales. This is the hair. As the cells at the base of the hair continue to multiply, they add themselves to the length of the hair so that the latter is gradually made to project out of the follicle. The hairs of the head in this manner eventually grow to a great length. If the hair be shed, a new one is produced by a fresh outgrowth of those cells which cover the vascular papilla at the bottom of the hair follicle. There is a little depression in the epidermis at the place where the hair projects from the follicle, and into this, a sebaceous gland opens. Each of these glands has a duct and one or two secreting sacs entirely filled with cells. The protoplasm of these cells, by changing into a fatty material, forms the secretion known as *sebum.* White pimples on the face commonly arise from the inflammation and distention of the sebaceous glands.

Attached to each hair follicle are a few muscle-fibres, which, when in action, cause the hairs to stand on end. The power to move the hairs is remarkably developed in the cat. The hair muscles are controlled by certain nerves of the sympathetic system called the *pilo-motor.* By stimulating one or other of these nerves the hairs can be made to stand up on different parts of the cat's body.

The shaft of a fully grown hair consists of a core of dry horny cells united together, and covered on the outside by

a layer of cells which overlap one another like the tiles of a roof. If you pull a hair out of your head and, holding it in the middle, work it between your finger and thumb, the scalp or root end of the hair will always move away, while the other end moves towards your thumb. This is owing to the arrangement of the tile-like scales on the outside of the hair. Knowing this fact, you can undertake to tell with certainty the root end of any hair.

The fine hairs on the body and limbs of man are arranged as in the monkey, to point in certain directions, so as to shoot off the rain from the body when climbing.

The loss of hair comes about from the decay of the hair follicles. Moulds growing in the roots of the hair are the common cause of baldness. Patent hair-restorers form a most profitable source of income to advertising quacks and barbers, but in ninety-nine cases out of a hundred are worthless to the purchaser.

Hair becomes grey and white in colour owing to bubbles of air collecting between the cells in the substance of the hairs. The natural colour is due to granules of pigment in the cells. It is commonly said that the hair may turn grey from fear in one night; this, if true, is not to be easily explained, for we know of no means by which the hairs could be thus influenced.

The feathers of birds, horns and claws of beasts, quills of porcupines and hedgehogs, scales of snakes and fishes, are all epidermic outgrowths modified in various ways.

The regulation of the heat of the body. The temperature of a man's body scarcely varies.

Take your temperature in the mouth with a clinical thermometer on the coldest day, and even when shivering with cold, it will be almost the same as in a Turkish bath, or on the hottest day in the summer. The thermometer will indicate in each case about $98\frac{1}{2}°$ Fahrenheit, or $37°$ Centigrade. During hard exercise on a hot day the temperature may rise to $101°$ F.

While the temperature of the body within is constant, the warmth or coldness of the skin depends at any time on the amount of blood circulating through it. The hand of another person will feel to you hot or cold according as your or his hand is the most flushed with blood. No sure sign as to the warmth of another person's body can therefore be drawn by feeling the skin. Recourse must be had to a thermometer, and this is best placed either in the mouth or rectum. In the latter place the temperature of animals and infants is most easily taken. The organs of a man's body will continue to work properly only so long as the temperature is kept uniformly about $98\frac{1}{2}°$ F. Should it either rise or fall a few degrees, the functions are disordered, and if the change be maintained life becomes endangered. The temperature is kept uniform by the control (1) of heat production, (2) of heat loss.

Heat production. All the living active tissues produce heat, owing to the processes of oxidation which go on within them. Heat is especially produced in the muscles, for there energy is continually set free by the breaking down of the complex contractile substance and the formation of the simple waste bodies—carbon dioxide and water.

Three bumble-bees, buzzing about in a little bottle, will be found to raise the temperature therein two or three degrees. The temperature in a beehive when the weather is frosty and the bees torpid may be $-1°$ C. On tapping the hive and arousing the bees to activity, the temperature may rise to 20° C.

In the liver, heat is probably produced whenever proteid is broken down into glycogen and urea. Each contraction of the heart helps to warm the body. The heart's force is spent in driving the blood through the small arteries and capillaries, that is to say, it is turned into heat. In all these and other ways, heat is constantly produced, and the circu-

lation, acting like a system of hot-water pipes, distributes the heat evenly to all parts of the body. In cold weather the heat production is increased, for man becomes more active; an omnibus driver or policeman beats his chest with his hands and stamps his feet on the ground. By increasing muscular activity, more contractile material is oxidised, and more heat liberated. At the same time, a man eats more in cold weather to maintain a sufficient supply of combustile material. In hot weather, a man eats less and tries to avoid effort.

Heat loss. Heat is lost in the urine, faeces, and expired air, but chiefly from the skin. In cold weather the skin is constricted, and the excretion of sweat diminished; thus the loss of heat by radiation and evaporation is reduced. At the same time a man can put on more clothes, and so limit the loss of heat. When a hot body is surrounded by one or more jackets with *layers of air between* each, the loss of heat is remarkably diminished. A single layer of linen, covering the whole human body, is said to diminish the loss of heat by two-thirds.

Clothes. The warmth of a garment depends upon the amount of air which is kept stationary by being entangled in its spongy meshes. Clothes prevent the loss of heat by convection, for the air, when warmed by the body, cannot rise, owing to the garments which entangle it. Air is at the same time a bad conductor of heat. If several garments are worn over one another they can be made of the lightest material, for air is entangled between them. The garments must fit closely to the body so that they cannot be displaced by the wind. Woollen clothes are warmer than cotton, owing to their spongy texture. White reflects away most sunlight and is therefore coolest, black absorbs most.

In the matter of clothing the man of sense is never the slave of fashion. The human body is too perfect a structure to be distorted by tight boots and corsets. Artists who paint the highest ideals of beauty do not choose the victims of fashion for their models, but portray the beautiful lines and natural curves of the figure.

When you see a tight and pointed shoe, think of the ugly, cramped, and corn-covered foot within; and when viewing a woman with a waist tightened to the shape of a wasp, remember the distorted liver, the cramped diaphragm, and the stomach impeded in the movements of digestion. By tight-lacing, the lower part of the chest is rendered contracted and immobile, while the upper part becomes unduly expanded and mobile.

The garments, which it is the fashion of to-day to call beautiful, in ten years' time become an object of ridicule. A few years ago no woman might ride a bicycle, now it has become the cult of all, and women who so loudly declaimed this healthy exercise as vulgar, gladly mount their machines. He, who blindly follows fashion, loses the strength of individuality and treads in the footsteps of the folly of others.

The power of man to withstand heat and cold. By the control of the loss and production of heat the temperature of the body is exactly balanced under the most diverse conditions. A man can for a short time remain alive and unharmed in a Turkish bath or oven heated to the boiling-point of water, that is to say, so long as the air is dry. Provided with felt slippers he could stand there while his dinner cooked beside him. He is able to do this owing to the profuse perspiration which pours from his skin and cools his body by evaporation. If the oven were full of steam the man would be instantly killed, because the evaporation of the sweat

would be prevented. You know from your own experience, that dry heat can be borne more comfortably than close damp heat. In some parts of the tropics men have to bear, for days in succession, heat even ten or twenty degrees higher than that of their bodies (Fahrenheit). This is bearable so long as it is not accompanied by damp.

In the arctic regions, on the other hand, men withstand a temperature far below zero.

The heat-controlling mechanism can be developed by habit. Boys by practising exposure to cold can accustom themselves to be naked for long periods of time. Darwin, describing the natives of Tierra del Fuego, tells how he fell in with a mother and babe both nude, and unconcerned at the sleet driving down upon them.

In the clothing of children a line must be carefully drawn between prudence and coddling. To over-clothe the body of a child in whom the energy of life and production of heat are great, to shut up the windows of the nursery and over-heat the room, to prevent the child from going out and roughing the weather, are the ways to court disaster. Development of the brain, the eye, the muscles, only come with use, and so is it with the vigour of circulation, and the power to withstand and enjoy hardship.

Source of animal heat. When a man is neither gaining nor losing weight, the energy which he gives forth daily in the shape of work and heat must come from the food that he is taking in. If an equivalent quantity of food be burnt in a calorimeter, the energy it contains can be exactly estimated (see Chap. II). If the man be enclosed in a large calorimeter, the amount of heat he gives off during the day can likewise be estimated, and, at the same time, he may be set to do work in lifting weights. The work

done can be estimated from the total weight raised, if this be multiplied by the height of the lift. From the heat given off, and the work done, the total energy of the man is calculated. When this is compared with the energy contained in his food the two quantities are found to be the same. About one-sixth of the energy of the food absorbed by the man usually appears as work, and five-sixths as heat. A given weight of fat, when burnt in a calorimeter, will give off twice as much heat as the same weight of proteid or carbohydrate, and therefore more fat is eaten in cold weather. The Esquimaux eat large quantities of blubber. The fat deposited under the skin acts as a non-conductor to heat, thus warm-blooded animals, like seals and whales, who live in ice-cold water have an enormously thick coating of blubber. Cold-blooded animals do not regulate their body heat. A frog's body becomes colder in winter and warmer in summer. They have no means of withstanding excessive changes of temperature. A frog cannot live in the hot summer sun, he must seek a cool and shady ditch or well. In winter, he avoids the frost by retiring to the bottom of a pond, for the temperature of the water cannot sink below zero. In summer, the frog is active and lives a fast life, for its protoplasm is stimulated by warmth. In cold weather, the protoplasm is numbed, and life at the lowest ebb. In summer, the frog excretes much carbon dioxide and eats plentifully; in winter, the metabolism of its body almost ceases, it requires no food, the muscles are scarcely used, and the output of carbon dioxide very slight. A hot-blooded animal like man behaves in just the opposite way; in winter, he is more active, and excretes more carbon dioxide in order to maintain his temperature. Some of the animals in Australia, such as the platypus, can partly control their temperature.

Among all animals, birds are the warmest, owing perhaps to the intense muscular energy required for flight. The

temperature of a hen is as much as 105° F., a dangerously high fever heat for man. The smaller the animal the higher is its temperature, and the more intense the metabolism of its tissues. This is so because the cooling surface in proportion to the body weight is greater in the smaller than in the larger animal.

Hybernating animals like dormice and bats are very curious, for these when cooled have the power to become like frogs, and thus sleep benumbed through the winter time. When warmed to about 50° F. such animals suddenly awake and become active. Their bodies then rapidly return to blood heat, and remain exactly regulated at this temperature during the continuance of the summer. They eat plenty of carbohydrate in the autumn and turn it into body fat. When waking in the spring they turn some of this fat into sugar and use this for the energy of their movement and body heat. An unhatched chick in its egg behaves like a cold-blooded animal, and is cooled and killed by lack of external warmth. So soon as the chick begins to peck its way out and escape from the shell, it becomes able to regulate its temperature. This wonderful change in nature has been observed to take place in the course of a few minutes. The power of control arises from increased production of heat, owing to the muscular activity of the chick, and from diminished loss due to the drying of its soft down.

CHAPTER XXIX

THE NERVOUS SYSTEM.

THE nervous system consists of (1) the brain, enclosed in the skull cavity; (2) the spinal cord, which is continuous with the brain and lies in the vertebral canal; (3) the nerves, which issue from the brain as well as from the spinal cord, and which supply all the organs of the body. There are two classes of nerves: the one kind carries impulses from the sense organs to the central nervous system, i. e. to the brain and spinal cord; by the other kind, impulses are carried from the central nervous system to the various organs. In the brain, the former kind of nerves arouse sensations of sight, sound, smell, warmth, pressure, &c., out of which, in man, a consciousness arises of the conditions in the world around him. The nerves of the second kind conduct messages from the spinal cord and brain by which the skeletal muscles, the glands, the vascular system, &c., are controlled, so that the work of each may lead to the common weal of the whole.

Nerves. By dissecting off the skin of a dead rabbit you may find, lying in the connective tissue beneath the dermis, fine white threads. These branch into filaments which enter the dermis and become finally lost to view. On separating the muscles, similar threads will appear, branching and ending

in their substance. These threads are the nerves. Seek for one of the larger nerves, say the sciatic nerve, which lies buried in the muscles at the back of the thigh. Having found this white cord, trace it upwards, cutting through each successive structure which conceals it from view. In doing so, you will have to cut through the hip-bone, for the nerve passes through the pelvic basin and finally reaches the lower part of the vertebral column. Here the sciatic nerve divides into several branches, and these disappear into the vertebral column, where they join the lower end of the spinal cord.

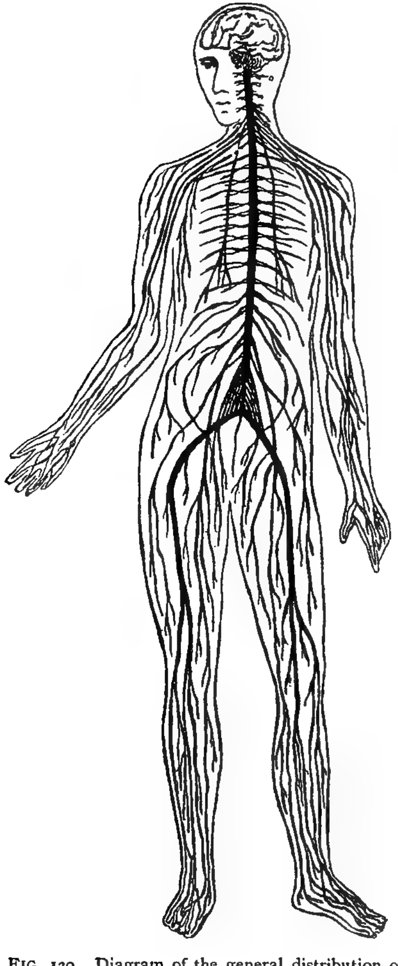


FIG. 129. Diagram of the general distribution of the nerves in man.

Next remove the skin from the back of the rabbit and dissect away along the whole of its length the muscles which cover the vertebral column. With a strong pair of scissors cut away the spinous processes of the vertebrae, and then insert the point of one

blade between the arches of any two vertebrae about the middle of the spine. The blade will now lie in the vertebral canal, and, by keeping this blade within and cutting away the arches both upwards and downwards, you can expose a soft white cord. This is the spinal cord. The dissection is difficult, and must be done with great care. The point of the blade within the vertebral canal must be kept hard against the bony arches so as not to injure the spinal cord.

At the point where the vertebral canal opens into the skull cavity you will find the spinal cord join the brain. At the level of the lumbar vertebrae the spinal cord tapers to a filament, and is surrounded by a leash of white nerve-roots: this part is called the *cauda equina*, or horse's tail. The nerve-roots forming the cauda equina arise from the spinal cord and pass out through openings between the lower vertebrae, and some of them you will find are continuous with the sciatic nerve.

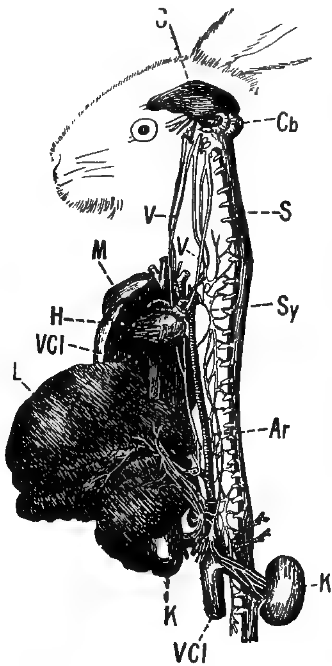


FIG. 130. Nervous system of rabbit. Ar. Aorta. C. Cerebrum. Cb. Cerebellum. H. Heart. M. Lungs. S. Spinal cord with nerve-roots cut short. Sy. Sympathetic chain of ganglia sending fibres to L. liver. K. kidneys and intestines. V. Vagus. VCI. Vena cava inferior.

Choosing any other nerve in the body for dissection (excluding the cranial nerves which arise from the brain), you would find, on tracing it, that it too entered the vertebral canal and ended in the spinal cord.

From the spinal cord, at regular intervals along its

length, and on either side, nerves are given off in pairs. There are in all thirty-one pairs of spinal nerves. The nerves of a pair arise one from each side of the cord, and pass out between the arch of one vertebra and that of the next. Thus, between every two vertebrae, the whole way down the spinal column (including the vertebrae that form the sacrum), a nerve passes out on either side to supply the skin and muscles on the right and left side of the body respectively. In the thorax the arrangement is most regular, for each pair of nerves, on leaving the vertebral canal, circles round the thorax, and supplies the area between a corresponding pair of ribs. Similarly, nerves issuing between the cervical and lumbar vertebrae circle round the neck and abdominal wall respectively, and supply both the skin and muscle there. Several of the nerves which leave the vertebral canal in the cervical and lumbar regions are, however, much thicker, for they not only supply the body wall, but end large branches which join together to form the nerves which course down the limbs. The spinal cord is thickened at the parts where these two large groups of nerves arise, forming *the cervical and lumbar enlargements.*

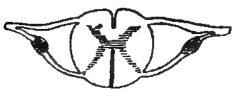


FIG. 131. Cross section of the spinal cord, showing grey and white matter, and anterior and posterior nerve-roots. Ganglion on posterior root.

Roots of the nerves. Afferent and efferent nerve-fibres. On picking up any nerve at the point where it leaves the spinal cord, you will find that it arises by two roots. One of these issues from the back and the other from the front of the cord. They are called the anterior and posterior roots. The roots quickly join together to form the nerve, and, at the place where the two join, there lies a little swelling on the posterior root called a *ganglion.* The ganglia of the spinal nerves—for every

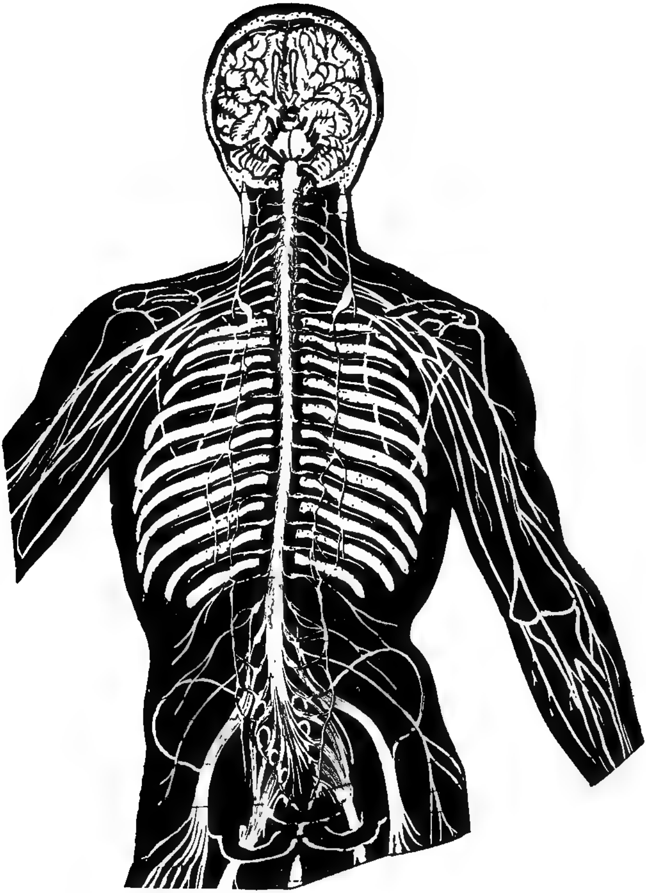


DIAGRAM OF THE NERVOUS SYSTEM. The whole of the face and viscera and the front of the skull and spinal column are removed. The ribs and bony wall of the skull are shown white dotted with black. The shoulder, hip, and arm bones are outlined in white. The cerebrum occupies the upper three-fourths, the cerebellum the lower fourth of the cranium. The pons and spinal bulb occupy the middle of the lower part of the cranium. The cranial nerves (black) are shown arising here. The spinal cord is seen ending below in the cauda equina. Notice the nerves arising from the spinal cord and the ganglion on each nerve-root. Notice also the large nerves going to the arms and legs.

nerve has one—lie concealed in the holes between the vertebrae through which the nerves issue.

Now it has been proved that if the posterior roots of the nerves are severed, say of all those which supply the right leg, the animal will be unable to feel any prick or touch in that leg. Sensation is paralysed, and therefore the posterior roots are *afferent*, they carry *sensory impulses* from the leg *to* the spinal cord. In other words, the sensory nerves enter the cord by the posterior roots. If, on the other hand, the corresponding anterior roots be cut, the leg will hang limp, and the animal will not be able to move it. It will, however, be able to feel a prick or pinch. The anterior roots carrying *motor impulses* to the muscles *from* the spinal cord are termed *efferent*. From these important experiments it becomes clear (1) that the nerves carry sensations to the spinal cord, (2) that the muscles are controlled by impulses which pass down the nerves from the spinal cord, (3) that the sensory impulses enter by the posterior roots, (4) that the motor impulses issue by the anterior roots.

Sympathetic ganglia and nerves. From each nerve, excluding those in the neck, there likewise arises a small branch to the viscera. These branches pass to join a chain of little ganglia lying on the front of the vertebral column and on either side of it at the back of the abdomen and thorax. The double chain of ganglia, and the nerves which join them together, form the *sympathetic system*. Nerves leave the sympathetic ganglia to supply the viscera. Some of the sympathetic fibres go to the heart and may excite it to beat faster, others maintain the tone of the arteries all over the body, while others pass to the intestines and spleen, and control the contraction of these organs. In addition to such efferent visceral nerves there are other fibres in the sympathetic system which bring

impulses from the viscera to the spinal cord, and are thus afferent in nature.

From the above account you will have learnt (1) that there are thirty-one pairs of spinal nerves, (2) that a pair of nerves issues between every two vertebrae, (3) that each nerve arises from the spinal cord by a posterior and an anterior root, (4) that the posterior root in each case has a ganglion upon it, (5) that the nerves, on issuing from the vertebral canal, divide into large branches which supply the body wall—both skin and muscle, (6) that at the same time many of them send a small branch which joins the sympathetic chain of ganglia, and so supplies the viscera, (7) that each nerve contains both afferent (sensory) and efferent (motor) fibres, (8) that the afferent fibres are connected with sensory nerve-endings and enter the spinal cord by the posterior root, (9) that the efferent fibres are connected with motor nerve-endings in the muscles and issue from the spinal cord in the anterior root, (10) that a man with all his posterior roots cut cannot feel, while a man with all his anterior roots cut cannot move his body or limbs.

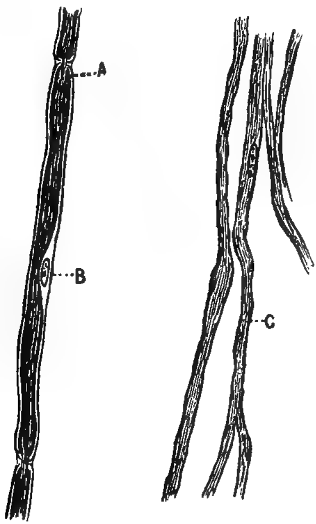


FIG. 132. Microscope, high power. Medullated and C non-medullated nerve-fibres. A. Node. B. Nucleus. Notice the external sheath and the axon crossing the nodes while the medulla is interrupted there.

Structure of the nerves. Take a small piece of nerve from a rabbit or frog, and with needles separate it lengthwise on

a glass slide. It can be pulled apart into silky threads. Take one of the threads, fray this out as finely as possible on a clean slide, add a drop of saline solution, and examine under the high power of the microscope. You will now see the constituent nerve-fibres. These are bound up in bundles, and the bundles are wrapped together by connective tissue to form the nerve. They appear as exceedingly slender white threads with a well-marked wavy outline. The breadth of the nerve-fibres varies considerably; some are half as broad as a red corpuscle, and others about as broad or even broader. It would take about 4000 average-sized nerve-fibres to cover an inch when placed side by side. The structure of the fibres can be made out by adding certain stains and reagents to the preparation. Each fibre consists of a soft central strand of protoplasmic substance called the *axon* or *axis cylinder.* Outside this is a sheath of white fatty material called the *medulla.* The medulla, in its turn, is enclosed by a thin membrane, the *neurilemma.*

The axon is the process of a nerve-cell, and extends as an unbroken strand from the nerve-cell to its termination. The axons of the nerves end in branches, either forming what is termed an end-plate attached to a skeletal muscle-fibre, or terminating in contact with sense-cells in a sense-organ. The axon is the essential part of a nerve-fibre. The medulla is a fatty substance which not only protects and nourishes the axon, but separates it from other axons in the surrounding nerve-fibres. This coat perhaps acts as an insulating material, just as electric-bell wires are covered with waxed thread to insulate them, and to prevent escape of the current. The neurilemma ensheathes the fatty material and holds it together. Along the course of a nerve-fibre, little breaks in the medulla may be seen placed at regular intervals. These are called nodes, and through these the lymph soaks to nourish the axons. Midway between any two nodes there lies, underneath the neurilemma, a nucleus. The nerves are supplied with arteries which form a network of capillaries round the nerve-fibres.

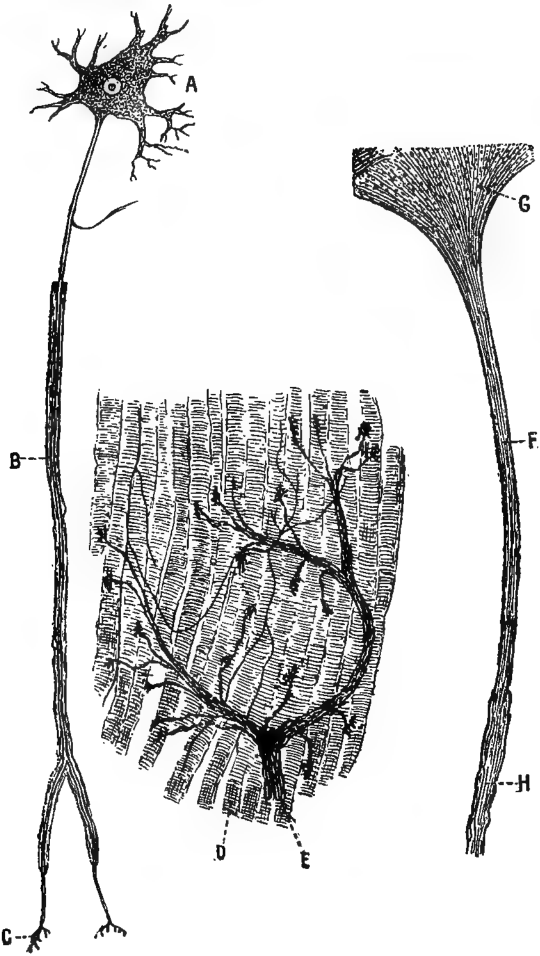


FIG. 133. A. Diagram of nerve-cell with dendrites and one axon. B. Axon becoming a medullated nerve-fibre. C. Axon terminating in branches. D. Striated muscle-fibres. E. Nerve-fibre ending in end plates on the muscle-fibres. F, G, H. Axon leaving A, highly magnified. After Stöhr.

In the sympathetic system many of the fibres, after leaving the chain of ganglia, are found to have lost their medullary coat. These are called non-medullated nerve-fibres.

Excitability of nerve. If the sciatic nerve in the leg of a decapitated frog be excited by a pinch, a hot wire, a chemical irritant, or an electric shock, the muscles of the leg will in each case contract. It has been determined, by noting the time at which contraction

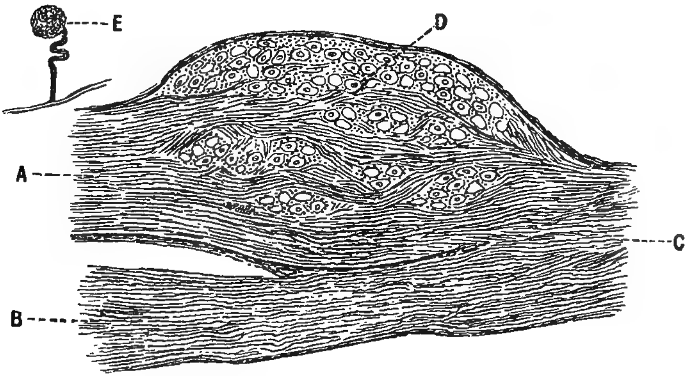


FIG. 134. Microscope, low power. Section through a ganglion on a posterior root. A. Posterior root. B. Anterior root. C. Common nerve-trunk. D. Ganglion cells among which course the nerve-fibres. E. A ganglion cell teased out to show T-shaped junction with a nerve-fibre.

of a muscle follows after stimulating its nerve, first near the muscle and then far off (near the spinal cord), that an impulse travels down a nerve at a rate of about 100 feet a second. We know of no change taking place in a nerve during the passage of an impulse except in its electrical condition. A nerve, when excited, causes a muscle to contract just as an electric wire transmits the current which explodes a torpedo. *As to the nature of nervous impulse we know very little.*

Ganglia. If one of the ganglia from a posterior root, or the sympathetic chain, be teased up with needles and examined under the microscope, it is found to be composed of nerve-cells and of nerve-fibres. Nerve-cells can be more easily obtained for observation from the spinal cord.

The spinal cord. Purchase the spinal cord of an ox from the butcher. (Ask him for the marrow out of the spine.) Cut

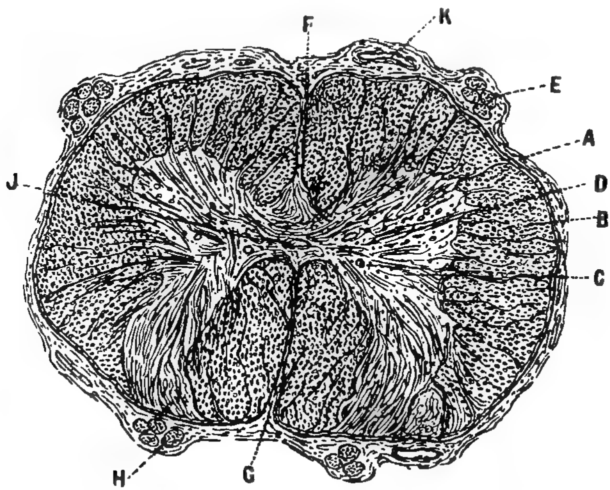


FIG. 135. Microscope, low power. Section through the spinal cord. A. Vascular coat, the pia mater. B. Medullated nerve-fibres C. Grey matter. D. Nerve-cells in anterior horn of H-shaped grey matter. E, H. Nerve-fibres of anterior and posterior root. F, G. Anterior and posterior fissure. J. Central canal of the spinal cord. K. Blood-vessel in pia mater.

this across with a sharp knife, and, by examining the cut ends, make out the following points. The cord is clothed with a vascular membrane, the *pia mater*, and is composed partly of a white substance lying on the outside and partly of a pinkish grey substance lying within. The grey matter is arranged roughly in the form of an H. There are two crescent-like masses of grey substance lying one in each half of the cord, and joined by a narrow bridge of the same material which crosses the

middle of the cord. The white matter surrounds the grey crescents. The cord is almost divided into halves by an anterior and posterior fissure, each of which runs inwards from the outside toward the bridge of grey matter. The anterior fissure is a distinct gap lined with pia mater which conveys blood-vessels to the central parts of the cord; the posterior fissure is not a gap but a connective-tissue partition. The two halves of the cord are exactly similar to each other. In the middle of the bridge of grey matter there is a little canal. This runs the whole way up the spinal cord, and is called the *central canal.* It cannot, however, be seen with the naked eye. The part of each grey crescent lying in front of the grey bridge, that is on either side of the anterior fissure, is called the *anterior horn*; the part behind, the *posterior horn.* There are thus two anterior and two posterior horns and a bridge of grey matter. Wherever you cut the cord across you will see the same arrangement of grey and white matter, so it is clear that the cord is composed along its whole length of an H-shaped column of grey matter surrounded by white matter. The anterior roots of the nerves arise from the anterior horns of the grey column, while the posterior roots enter the cord near the posterior horns.

FIG. 136. Microscope, low power. Nerve-cell teased out from the grey matter of the spinal cord.

Take some of the white matter and tease it up on a slide; it will appear under the microscope to be composed of nerve-fibres. To see the structure of the grey matter proceed as follows. Keep a piece of the cord in a little dilute alcohol (1 part

methylated spirit and 2 parts water) for a few days to soften it. Then with a spoon scoop out some of the grey matter and put this in a test-tube with a little dilute glycerine and a few drops of red ink. Thoroughly shake the mixture in the test-tube, allow the sediment to fall to the bottom, and mount a drop of this sediment on a glass slide. Under the high power of the microscope you will find the sediment is chiefly composed of granules of fat from the medullary coat and other fragments of nerve-fibres, but among these there are scattered, here and there, nerve-cells stained by the ink. Some of these are comparatively large, i.e. ten or fifteen times the diameter of a red blood corpuscle. It would take probably 250 of them, laid side by side, to cover an inch. The cells have large nuclei and are remarkable for having many branching processes.

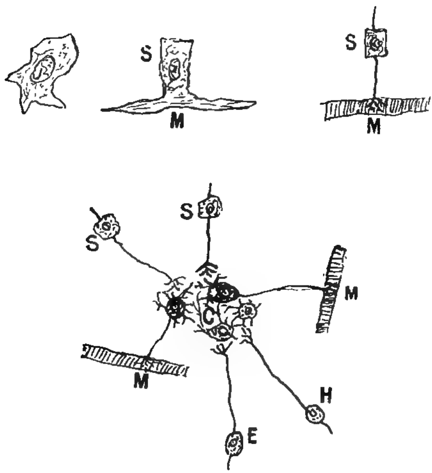


FIG. 137. Diagram of the evolution of a nervous system: firstly, an amoeba; secondly, a cell of a hydra—outer part S feels, inner part M moves; thirdly, a sense-cell S connected to a muscle-fibre M by a nerve-fibre; fourthly, tactile cells SS, visual cell E, auditory cell H, sending nerve-fibres to brain C. This is composed of association cells, and motor cells which send nerve-fibres to muscle-fibres M.

Structure of nerve-cells, axons, and dendrons. Now it has been proved by special means that each nerve-cell has one long process which becomes the axon of a nerve-fibre, and a number of short processes called dendrites. It is in the anterior horns of the grey matter that the large nerve-cells lie; their long processes pass off as the axons of the

anterior roots and end in the muscles, while their short processes interlace in the grey matter to form a felt-work. The grey matter is composed of nerve-cells and a felt-work of dendrites. In the posterior horns there are fewer and smaller nerve-cells, and their axons do not pass out of the cord, but end somewhere in the grey matter. The axons of the fibres in the posterior roots arise from the nerve-cells situated in the ganglia of these roots. In these ganglia, each of the cells has a T-shaped process, and, while one branch of the T passes down to a sense-cell and ends in branches round that, the other branch passes up the posterior root and enters the spinal cord. Having reached the spinal cord the posterior root-fibres run up towards the brain, but during their upward course they send off twigs, both upwards and downwards, to join the felt-work of the grey matter of the spinal cord. Finally, the posterior root-fibres end by joining the felt-work of dendrites round certain nerve-cells situated in the grey matter of the spinal bulb. From the cells in the spinal bulb there arise other axons which pass up to the grey matter of either the great brain or cerebellum, and end in the felt-work of dendrites around the cells situated there.

From the above description it is clear that impulses starting from sense-cells in the skin can, on entering the spinal cord, not only pass into the felt-work of the grey matter of the spinal cord and influence the anterior horn-cells, but also pass up to the brain and influence the cells in the spinal bulb, the cerebellum, and the cerebrum. The posterior root-fibres form the column of white matter in the hind part of the cord. The columns of white matter in the front and sides of the cord contain three important sets of fibres: (1) a set which descends from the cerebrum. These fibres are the axons of cells situated in the cortex of the great brain, and they end by joining the felt-work round the anterior horn-cells. By means of

these fibres the brain can influence the anterior horn-cells and set the muscles in motion. (2) A set of fibres which ascend from the spinal cord to the cerebellum. These fibres are the axons of cells situated in the posterior horn and near the bridge of grey matter. (3) A set of fibres which pass from cells in the grey matter of the spinal cord to end in the felt-work of the grey matter at some other level of the cord. These fibres connect the different parts of the spinal cord together.

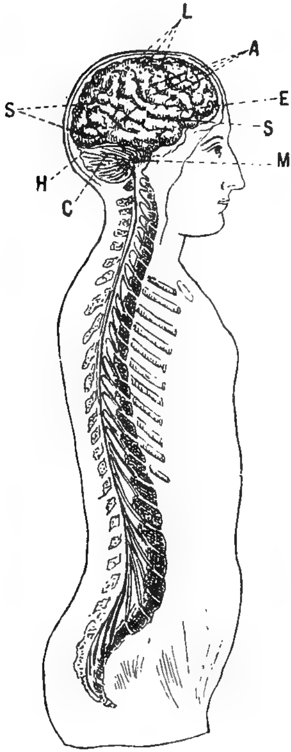


FIG. 138. Brain, spinal cord, and nerve-roots issuing from spinal cord. The chief areas are marked on the great brain. A. Area controlling arm. E. Face. H. Hearing. L. Leg. S. Speech. S. (at back of great brain) Sight. C. Cerebellum. M. Spinal bulb.

It may appear to you an impossible task to attempt to trace the course of the fibres in the spinal cord; nevertheless it has been done, and the above facts discovered in the following simple way. If the axons of any nerve-cells be divided from their cells they die and degenerate. When degenerated, they stain differently with certain dyes, and thus can be traced. Suppose some of the posterior roots be divided just where they enter the spinal cord; the nerve-fibres cut off from their ganglion cells will degenerate in the spinal cord, and, on cutting sections of the latter at different levels, the degenerated patch can be seen and so

traced upwards to the brain. Similarly, after injury to any part of the brain the degenerated fibres, which are the axons of the damaged cells, can be traced downwards in their course to other parts of the brain or to the spinal cord.

THE BRAIN.

The structure of the brain. So soon as the spinal cord enters the skull it swells out to form the stem of the brain. The first part of the stem is known as the *spinal bulb* or medulla oblongata. To the back of the spinal bulb there is attached a large mass of nervous tissue, the *cerebellum* or small brain. This occupies the lower part of the cranial cavity. The hand placed at the back of the skull between the occiput and the neck covers the part occupied by the cerebellum. The cerebellum is divided by a deep cleft into right and left hemispheres, and these are joined together by a remarkable bridge of nerve-fibres. The bridge or *pons* runs across the *front* of the spinal bulb from one cerebellar hemisphere to the other. It thus encircles the stem of the brain. Some fibres turn off from the stem of the brain just below the pons and on either side to join the cerebellum. These fibres form the *inferior peduncles* of the cerebellum, while the pons itself is composed of the two *middle peduncles* of the cerebellum.

Leaving the pons and the cerebellum, and continuing its upward course, the stem of the brain divides into two to form the *peduncles* of the great brain. The great brain, or *cerebrum*, consists of two hemispheres, and a peduncle passes into either. Just before cleaving into the two peduncles of the cerebrum the stem of the brain swells out behind into four little lumps. These are placed close together on the hinder surface of the stem and are called the *corpora quadrigemina*. The part of the stem lying between the cerebellum and the cerebrum, where

these bodies are situated, is called the *mid-brain.* Each hemisphere of the cerebellum sends some fibres to join the mid-brain; these fibres form the *superior peduncles* of the cerebellum. Thus the cerebellum has six peduncles in all. The two inferior peduncles connect it with the spinal cord; the two middle peduncles connect the two cerebellar hemispheres with the pons and spinal bulb; the two superior peduncles connect the cerebellum with the mid-brain and the cerebrum. On the other hand, each hemisphere of the cerebrum has a peduncle connecting it with the mid-brain.

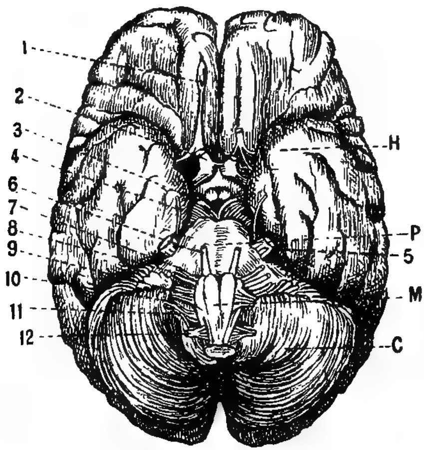


FIG. 139. Base of the brain. C. Cerebellum. H. Cerebrum. M. Spinal bulb. P. Pons. The numbers indicate the roots of the twelve cranial nerves.

The right and left cerebral hemispheres occupy the whole of the front and broad part of the cranial vault, reaching from above the occiput to the forehead. They are almost entirely separated from each other by a deep cleft; at the bottom of this cleft there runs a band of nerve-fibres bridging the two hemispheres together. This bridge is called the *corpus callosum.* The base of each cerebral hemisphere, where the peduncle enters, is occupied by masses of grey matter called the *basal ganglia.* The nerve-fibres which pass up the stem of the brain, and thence into the cerebral peduncles, finally dive into the substance of the cerebral

hemispheres and run to end in the basal ganglia, and in all parts of the *cortex*. The latter is the outside grey layer of the great brain. The cortex of each cerebral hemisphere is crinkled into a number of *convolutions*. Underneath the grey cortex the substance of the brain is composed of white nerve-fibres. The convolutions increase the area of the cortex enormously, and the greater the brain power of a man the more convoluted is his brain found to be. The grey matter of the cortex contains myriads of nerve-cells, each provided with many dendrites and one axon. The dendrites interlace to form the felt-work of the grey matter, the axons run off as nerve-fibres and form the white matter of the brain.

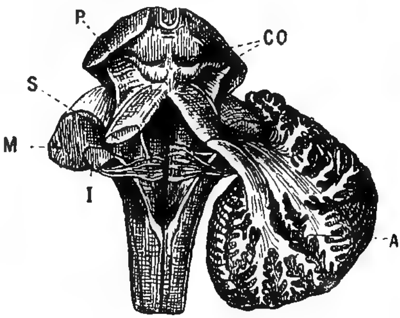


FIG. 140. Spinal bulb, peduncles of cerebellum and mid-brain. A. Part of one cerebellar hemisphere left and cut to show peduncles entering it. CQ. Corpora quadrigemina. I. Inferior peduncle. M. Middle peduncle. S. Superior peduncle. P. Peduncle of great brain.

Some of the axons cross from one hemisphere to the other through the corpus callosum, and thus unite the two halves of the great brain. Others join the cortex with the basal ganglia, and the different convolutions of each hemisphere together. A large number of the axons run from the cortex down the peduncles of the great brain. Some of these connect the cortex of the cerebrum to the cortex of the cerebellum; another group of fibres run either to the grey matter in the spinal bulb, or end at different levels in the grey matter of the spinal cord. Axons likewise ascend in the stem of the brain to end in the cortex of the great brain; these arise from cells in the grey matter of the spinal bulb,

the cerebellum, and the mid-brain. Thus all parts of the central nervous system are linked together by means of relays of cells, axons, and dendrites.

The surface of the cerebellum is convoluted in a remarkable way, and it, too, is lined with a grey cortex and contains white matter within. The folds of the cerebellum, when cut, present a leaf-like arrangement, called the arbor vitae or 'tree of life,' for the ancient anatomists used to erroneously believe that the cerebellum controlled those functions on which life immediately depends, namely, the action of the heart and the respiration. It is the spinal bulb and not the cerebellum which is particularly bound up with these functions. The cortex of the cerebellum is composed of cells and a felt-work of axons and dendrons. The cells differ both in arrangement and size from those in the cortex of the great brain.

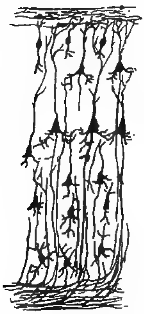


FIG. 141. Microscope, low power. Diagram of the cells in the cortex of the great brain. A. External layer of association cells, axons, and dendrons. B. Pyramidal cells which send off axons to enter the layer of medullated fibres C. The dendrons of the pyramidal cells pass into layer A.

The sheep's brain. To further study structure of the brain, obtain a sheep's head from the butcher, and ask him to saw it in twain from snout to occiput. The sheep's brain is very small and not to be compared in size with that of a man; the general arrangement of the parts is, however, the same. In each side of the cranial cavity you will see one-half respectively of the stem of the brain, of the cerebellum, and cerebrum. The brain is a symmetrical organ: the two halves are in every respect alike. In the cerebellum examine the curious folded arrangement of the grey and white matter, forming the arbor vitae. Cut open the cerebral hemisphere and observe the grey cortex and white inside. Examine the way in which the peduncle passes into the cerebral hemisphere, and also the manner in which the cerebellum is attached to the back of the spinal bulb. While

carefully removing the brain from one half of the head you may see some of the cranial nerves passing from the mid-brain and spinal bulb to escape through small holes in the wall of the cranium. On the other half of the head observe the partition which separates the cerebrum from the cerebellum, the membranes which surround the brain, and the blood-vessels coursing over its surface.

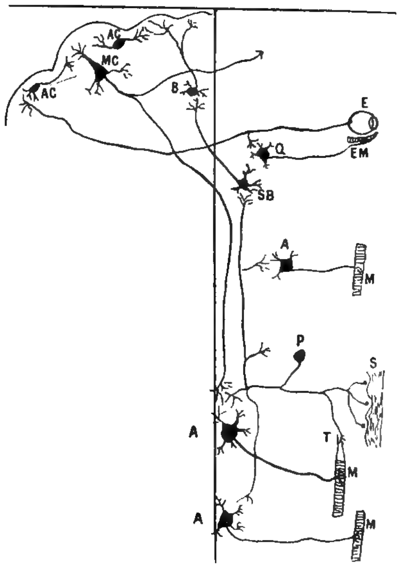


FIG. 142. Diagram of the course of some of the chief nerve-fibres. These are represented on one side only. S. Skin with sensory nerve-endings. T. Sensory nerve ending in a tendon. P. Ganglion cell in posterior root joined to afferent fibre by ⊥ process. Afferent fibre on entering spinal cord sends off twigs to motor cells A, and ends at the cell SB in the spinal bulb. From SB an axon goes to B, a cell in basal ganglia on opposite side of the brain. From thence an axon goes to the cortex of the great brain. AC. Association cell in cortex. E. Eye. Axon from retina sends off a twig to a cell in Q, corpora quadrigemina. This is a motor cell for the eye muscle EM. The axon from the retina then crosses to end in the cortex of the great brain on the opposite side. MC. Motor cell in cortex which sends off an axon; this crosses over in the spinal bulb and goes to A. A. Motor cell in anterior horn of spinal cord which supplies M, the muscle-fibre.

Obtain from the oil-shop a couple of pounds of putty. Roll a piece of this into a cord, about as thick as the little finger, and twenty inches long. Thicken one end to about the size of the thumb, and for a space of two inches. Then divide this end by a cleft into two for a length of about half an inch. Call this cleft end the upper end, and call the surface of the cord lying on the table the front surface. Just

below the cleft, affix on the back of the cord four little round lumps, two on each side, and close together. Below these, attach a large lump also to the back of the cord.

Now the two short cords divided by the cleft represent the peduncles of the cerebral hemispheres. The four little lumps attached below the cleft are the corpora quadrigemina, and the part where these are attached is the mid-brain. The big lump below these is the cerebellum.

Make a bridge of putty pass from one side of the cerebellum to the other side. The bridge must pass underneath the putty rope, that is, across its front surface. The bridge is the pons, and it is formed by the two middle peduncles of the cerebellum. From the upper surface of the cerebellum make two little ropes of putty pass to join the mid-brain. These are the superior peduncles of the cerebellum. From the lower surface of the cerebellum make two little ropes pass, one on either side, to join the spinal bulb. These are the inferior peduncles of the cerebellum. The spinal bulb is the lowest part of the thickened end of the putty rope; the cerebellum rests on the back of this. The remaining eighteen inches of the rope represent the spinal cord. Make a cleft in the cerebellum behind, so as to divide it into right and left cerebellar hemispheres.

To complete your model add above to either peduncle of the great brain a lump of putty. These represent the masses of grey matter or basal ganglia, lying at the base of the cerebral hemispheres. Cover each of these with a very large lump to represent the cerebral hemispheres. Finally, join the two cerebral hemispheres together by a thin band of putty, i. e. the corpus callosum. From a frog killed with chloroform, remove the top of the skull with scissors, and examine the shape and size of the parts of its brain.

The membranes of the brain and spinal cord. The whole of the brain and spinal cord is clothed with a thin connective-tissue membrane, the *pia mater*. This membrane is extremely vascular, and the blood-vessels branching in it send off innumerable capillaries to penetrate the nervous substance and supply it with blood. The skull

cavity and the vertebral canal are lined with a strong fibrous membrane, the *dura mater.* Between the dura and the pia there is another very thin membrane, the *arachnoid.* The surface of the brain is moistened with a lymph-like fluid, the *cerebro-spinal* fluid. The brain is protected from injury by the great strength of the vault of the skull. The spinal cord is surrounded by the cerebro-spinal fluid. There are also large veins full of blood which lie between the bony wall of the vertebral canal and the dura mater. The cerebro-spinal fluid and the veins together act as a water-bed for the spinal cord, and help to break the effect of the jars or blows given to the spine.

The three membranes of the brain and spinal cord are known as the meninges, and may be the seat of fatal inflammatory disease—meningitis.

Weight of the brain. The average weight of the brain is about 49 ozs. for the male, and 44 ozs. for the female. The brain and head in the child are very large in proportion to the rest of the body. The brain grows very quickly till the fifth year, then very slowly, and after twenty the growth is not perceptible. The brains of distinguished men are often several ounces heavier than the average; they are not always so, for quality is as important as quantity. Both Byron's and Cromwell's brains are said to have weighed almost eighty ounces. The brains of idiots are small and badly developed. Man has gained pre-eminence over all animals owing to the enormous development of his brain in proportion to the size of his body. A whale measuring seventy feet long has a brain weighing only five pounds, and an elephant's colossal body is controlled by a brain of about eight pounds.

Cranial nerves. In addition to the thirty-one pairs of

spinal nerves, there are twelve pairs of cranial nerves which arise from the brain and issue through holes in the wall of the skull. These nerves arise in pairs from corresponding parts on each side of the brain. The brain, in contrast to the spinal cord, is enormously developed in size, owing to the fact that the nerves of the chief sense-organs enter here.

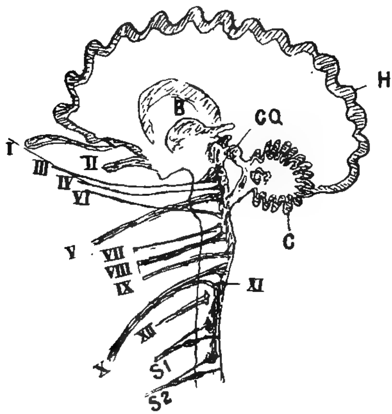


FIG 143. Diagram of the brain and cranial nerves. B. Grey matter at the base of the cerebrum. C. Cerebellum. CQ. Corpora quadrigemina. H. Grey cortex of cerebrum. S_1, S_2. First and second spinal nerves. I–XII. The cranial nerves.

1. The nerves of smell are the first pair. Arising from the base of the brain in its front part, the *olfactory* nerves give off a number of fine twigs which pierce the roof of the nose to end in the mucous membrane of its upper part.

2. The *optic* nerves are the second pair. Arising from the mid-brain these nerves pass forwards under the base of the cerebrum and interlace there, entering the orbits, supply the eye-balls. The optic nerve-fibres are widely connected in the brain, spreading into the grey matter of the corpora quadrigemina, the cerebellum, the basal ganglia, and the hind part of the cerebrum. If the hind part of the *right* cerebral hemisphere be totally destroyed in a man he cannot, when looking straight forwards, see any object on his *left side.* Rays of light from objects on the left side of a man strike the inner side of the left eye and the outer side of the right eye.

Take a long straight stick and place one end on some object on the left of you, and the other end against each eye in turn, looking straight forward all the time; you will then see that the rays of light, which pass from the object in lines straight as the stick, must strike the inner half of the left and the outer half of the right eye. Now the nerve-fibres from these two halves proceed to the right cerebral hemisphere, while to the left hemisphere the fibres pass from the other two halves, that is, the outer side of the left and the inner side of the right eye. Hence, if the left cerebral hemisphere be destroyed in its hinder part, the man will see nothing on his right side.

The optic nerves, by sending fibres to the grey matter in the mid-brain, control certain motor nerves which arise there and govern the movements of the eyes.

3. The third pair of nerves arises from the grey matter in the mid-brain, and supplies the muscles that turn the eyes upwards, downwards, and inwards. These nerves also control certain muscles within the eye, namely, the sphincter of the iris which contracts the pupil, and the ciliary muscle by means of which the lens of the eye is altered in shape so as to focus the images of near objects upon the retina.

4. Each of the fourth pair of cranial nerves arises from the mid-brain, and supplies one of the muscles of the eyeball, which helps to control the downward movement of the eyeball.

5. The fifth nerve arises from the region of the pons in two roots. It contains both afferent and efferent fibres. The afferent root has a ganglion upon it like the posterior root of a spinal nerve, and supplies the outside of the eyeball, the lower part of the nose, the front part of the tongue, the mouth, teeth, and cheeks. The sensibility of these parts depends on the fifth nerve. The efferent fibres control the chewing muscles.

6. The sixth pair of nerves arises from the spinal bulb, and supplies the muscles which turn the eyes outwards.

The eye muscles are thus controlled by the third, fourth, and sixth nerves. Deficient action or paralysis of any one of these nerves causes the eye to squint.

7. The seventh nerve, arising from the spinal bulb, is an efferent or motor nerve, and supplies the muscles of the face. This is the nerve of facial expression.

8. The nerves of hearing are the eighth pair. The fibres of these nerves enter the spinal bulb just below the pons and spread out to form connections with the grey matter of the cerebellum, the mid-brain, and the cerebrum. The fibres from the right ear are connected with the left cerebral hemisphere, and those from the left ear with the right half of the great brain. Many of the fibres from the semicircular canals pass to the cerebellum.

9. The *glosso-pharyngeal nerves* form the ninth pair. These supply one or two of the pharynx muscles and are the chief nerves of taste. It is the opinion of some anatomists that the taste nerves have their *origin* in the fifth nerves, and join the ninth nerves.

10. The tenth pair, the important *vagus nerves*, passes off from the spinal bulb and descends through the neck and thorax as far as the abdomen, on their way sending off branches to the pharynx and oesophagus, larynx, windpipe and lungs, heart, stomach and intestine, pancreas and liver. These nerves contain both efferent and afferent fibres. The muscles of the larynx are controlled by these nerves, and they, together with the glosso-pharyngeal nerves, set in orderly motion the muscular coat of the pharynx and gullet by which the act of swallowing is carried out. The churning movements of the stomach and the secretion of gastric juice are likewise controlled by efferent fibres in the vagus nerves. These nerves carry fibres to the heart which constantly regulate the frequency with which that organ beats. The afferent fibres in the vagus nerves carry messages to the spinal bulb—(1) from

the larynx and lungs, by which the rhythm of respiration is controlled; (2) from the heart, by which the blood-pressure is regulated; (3) from the abdominal organs, regulating the action of these organs.

Considering all these facts it becomes clear that the function of most important organs, and the continuance of life itself, depend on the proper action of the vagus nerves and the grey matter in the spinal bulb.

11. The eleventh pair, the *spinal-accessory nerves*, arises from the upper part of the spinal cord as well as from the spinal bulb. They control certain of the muscles in the neck and send other fibres to join the vagus.

12. The twelfth pair, called the *hypoglossal nerves*, supplies the muscles of the tongue. The movements of the tongue in speech, and in swallowing, are controlled by these nerves.

CHAPTER XXX

THE NERVOUS SYSTEM (*continued*).

The seat of consciousness. If the nozzle of a pair of bellows were inserted into the windpipe of a criminal immediately after execution, and air were blown rhythmically into the lungs, then, granting that the body were kept warm and in the horizontal position, the tissues and organs might continue to live for many hours. The natural respiration of a man ceases so soon as his neck is broken and the spinal bulb is crushed; the organs die in consequence from lack of oxygenated blood. By means, however, of the bellows the blood can be artificially oxygenated; and in such case the heart would continue to beat, the blood circulate through the lungs and body, the intestines writhe with peristaltic movement, the kidneys secrete, and the liver alter the nature of the blood. The body of the man, however, would lie still, and no spontaneous movement of the muscles occur. Suppose, however, a nerve such as the sciatic were stimulated on its way to the muscles of the leg, then these would contract and the leg of the murderer would kick. Similarly, if one of the vagus nerves were excited, the fibres passing to the heart would cause that organ to beat more slowly. It is evident, then, that the tissues and the nerves are all alive and acting, but the man as a whole is dead, for the spirit of life or consciousness

passed from him at the moment when the structure of his brain was disorganised by the shock of the injury.

There was once a man who, holding out a piece of his own skull, begged for money in the streets of Paris. The upper portion or vault of his skull had been torn off as the result of an accident, and his brain lay exposed save for the strong fibrous covering of the dura mater. The wound otherwise was healed, and the man strong and well. Now for a small sum the beggar would allow any one to press upon his brain, and when this was done he lost consciousness, and, as it were, fell into a deep sleep. But when the pressure was withdrawn, consciousness returned and the man awoke from his sleep.

So soon as the blood is squeezed out of the cerebral hemispheres these organs cease to work, and consciousness vanishes. In like manner, a man falls down unconscious if he be clutched by the throat so that the two carotid arteries are compressed and the blood supply to the brain suddenly diminished. This is a method of seizure which street robbers have often employed in robbing their victims. When a person faints he loses power over his muscles and falls to the ground senseless with his limbs huddled in a heap. This is due either to sudden failure of the heart or to loss of vascular tone. The blood in either case passes to the dependent parts of the body, and the circulation through the brain ceases. Recovery is brought about by placing the head of the sufferer on a lower level than the body, so that the blood may run to the heart and brain. Similarly, a violent blow on the head will, by disorganising the delicate structure of the brain, instantaneously rob a man of consciousness. After such an injury he may die, or else lie for hours, days, or even weeks, in a complete state of insensibility, and finally, according as repair takes place, recover either the whole or part of his wits.

By breathing in such poisons as ether, chloroform, or carbon dioxide gas, by drinking infusions of poppy containing the drug opium, the quality of the blood is so altered that the brain ceases to act and consciousness vanishes. Before the loss of consciousness becomes complete the disorder of the brain is shown by the wild dreams, the struggles and cries which occur under the influence of one or other of these drugs. It is abundantly clear, then, that consciousness depends on the condition of the brain.

In order that consciousness may persist, the structure of the brain must not be unduly shaken, while the chemical substances of which it is composed must be supplied with pure oxygenated blood. More than this, the brain must be continually aroused by the instreaming of sensory impulses, for out of these there arises consciousness of our life and its surroundings. At every moment of our waking time waves of energy are sweeping against our bodies; energy of light, sound, heat, the pressure and contact of substances, their smell and taste excite the different sense-organs, each of which is fitted to transform one or other kind of energy into nerve impulses. So soon as we become fatigued with the day's work we retire to a quiet and dark room, lie upon a comfortable bed which gives equable pressure to our bodies, cover ourselves with blankets to promote a uniform warmth, and then fall asleep. Owing to the withdrawal of all exciting sensations consciousness slumbers. There is a case reported of a man who, having lost all sensibility, except in one eye and one ear, straightway fell asleep whenever these remaining sense-organs were closed. When the neck of a man is broken, consciousness and respiration cease together; but in the case of the French beggar consciousness vanished while the respiration continued, that is to say, so long as the pressure on his brain remained moderate in amount. The difference between the two cases lies in the fact that consciousness

depends on the activity of the grey matter of the cerebral hemispheres, while respiration is controlled by the grey matter in the spinal bulb. If forcible pressure had been made on the brain of the beggar, the spinal bulb would have been rendered bloodless, and respiration ceasing, the man would have died. So, too, *anaesthesia* can be safely produced by a moderate dose of chloroform, for the cortex of the cerebrum is rendered inactive more easily than the spinal bulb, and thus respiration continues while consciousness ceases. If pushed too far, this drug may occasion death by poisoning the grey matter of the spinal bulb or the tissue of the heart itself. In the case of a man who has been over-chloroformed, drowned, or suffocated, recovery may generally be brought about by means of artificial respiration, that is to say, so long as the heart has not ceased to beat. The brain in these cases recovers so soon as it receives oxygenated blood. On the other hand, the man whose neck has been broken cannot recover consciousness, even though his blood be artificially oxygenated, for the structure of his brain has been too far disorganised by the injury.

From the above observations we may conclude (1) that a man loses consciousness so soon as his cerebral hemispheres cease to act, (2) that a man whose spinal bulb is disorganised not only loses consciousness, but dies from cessation of respiration.

The effects which follow severance of the spinal cord. Now let us consider the case of a man who, by falling downstairs, has fractured his spine and severed the spinal cord, say in the region of the upper dorsal vertebrae. This man will be conscious, his speech and memory will be unaffected, his respiration will continue. He will, however, have completely lost both sensibility of, and power over, his legs and the part of

his body below the seat of injury. On more carefully examining the sensibility of such a man, a girdle-line can be traced round his body, dividing the sensitive from the insensitive part. Moreover, on observing the respiratory movements, you would find that the intercostal muscles, supplied by the spinal nerves below the seat of injury, were not working, while the diaphragm remained in full action. This is explained by the fact that the diaphragm is supplied by the phrenic nerves which leave the spinal cord in the neck, that is to say, above the seat of injury. The man feels neither body nor legs, for the sensory impulses which enter the spinal cord below the injury can no longer reach the brain. Likewise, the man cannot despatch commands to the muscles of these parts, for the fibres are interrupted which connect the brain with the motor nerve-cells in the anterior horn of the spinal cord. The man, beside losing both power of movement and sensibility, will be unable to control the sphincters of the bladder and anus. Both the passing of urine and faeces will therefore take place involuntarily. On tickling the feet of the man while he lies paralysed in bed, his legs may suddenly jerk up; but of both the tickling and the movement, the man will remain entirely unconscious so long as he does not *see* his legs move.

Reflex action. The movement of the legs is brought about by what is termed a *reflex action.* The following is the course of events:—(1) The sensory nerve-endings in the feet are excited; (2) these send a message up the afferent nerve-fibres; (3) the fibres entering by the posterior roots pass upwards in the posterior columns and send twigs to join the felt-work of grey matter in the spinal cord; (4) the fibres are interrupted in their upward course by the severance of the spinal cord, so the brain is not excited by the tickling, and consciousness remains in

abeyance; (5) the twigs of the fibres entering the grey matter of the spinal cord can act on the motor cells in the anterior horn and cause these to discharge motor impulses; (6) the muscles contract and the legs are drawn away. The stimulus is reflected from the sense-cells up the sensory nerves, through the grey matter of the cord, down the motor nerves, to the muscles. The sensory impulses cause the spinal cord to discharge, not a wild convulsive movement, but one carried out by a particular group of muscles, and balanced so as to produce a definite and useful result. This can be well seen in a decapitated frog. The frog must be left quiet for an hour or two after the head has been severed, so that the spinal cord may recover from the shock due to the injury. If a drop of acid be then placed on the flank of such a frog, the leg on the same side will be drawn up, and the acid wiped off with the toes. If the acid be strong, both legs will be drawn up several times in succession, and the arms too may be thrown into movement. Suppose the eye be touched in a frog from which the cerebrum and the basal ganglia have been entirely removed. The animal will at once close the eye. If the stimulus be made stronger, the frog will also wipe the eye with its hand; while, if the stimulus be made still stronger, the frog will not only close and wipe its eye, but will move its head and trunk away. *These reflex actions are not accompanied with consciousness.* Such an experiment shows not only the fitting character of the movements, but proves that as the stimulus increases so does the motor reaction become greater. Intense stimulations spread more widely through the grey matter of the spinal cord.

Reflex action is always the same in form, whatever the kind of stimulus used. If the sole of the foot be tickled in a man whose spinal cord has been severed, the leg will be drawn away. If the sole be burnt or scratched, pricked

or whipped, the movement may be more or less violent, but it will always be of the same kind. While reflex actions are generally of a fitting character, that is to say, adapted to the preservation of life, they need not always be so. If a needle be placed just above the foot while the sole is tickled, the leg will reflexly be pulled up. Thereby the foot will be pricked by the needle. And however many times this experiment be repeated, the result will always be the same. Such reflex actions depend on pathways of conduction which were laid down in the nervous system during the process of infantile growth. The power of the spinal cord to carry out such actions cannot be modified by practice or experience.

Effect of removal of the great brain. Curiously enough no sensation is aroused on touching the cerebrum, although this organ is the seat of consciousness. A man's great brain, if exposed by injury, may be touched by the surgeon and yet the man remain entirely unaware of any such contact. If the cerebral hemispheres be destroyed by the bursting of a blood-vessel a man will sink into a deep somnolence. After destruction of the great brain an animal may, if fed by hand, continue to live, but in a completely idiotic condition. Such an animal is able to run about, and can swallow food if the same be placed within its mouth. It is disturbed by a loud sound, such as the blowing of a horn, and may perhaps avoid a bright flame if this be suddenly interposed in its path. On the other hand, all acts of intelligence on the part of the animal cease. It is unable to hunt for food, takes no notice of its fellows, and ignores the presence of men. Its time is spent in sleep or in aimless wanderings. When asleep the limbs may be gently placed in the oddest position, and it will pay no heed to this. A frog, in which the cerebral hemispheres have been destroyed, sits up in the ordinary way, hops when touched, and

avoids obstacles in its path, recovers its proper position when placed on its back, swims when thrown into water, and, by climbing up to the top when placed on a tilting board, maintains its balance. All these acts may be classed together as *automatic reactions* to stimulations. Such movements are more complicated in character than reflex actions, and are guided by more than one set of sensory impulses. In the case of the frog deprived of its great brain, a touch may cause the animal to hop forwards. Each hop, owing to the contact of the skin with the ground, arouses another hop. The instreaming of afferent impulses causes the animal to move automatically like a machine; it never moves spontaneously. It swims in water, owing to the contact of the water with the skin, but so soon as the water is removed the animal comes to rest.

The size of the cerebrum, when viewed in comparison with that of the spinal bulb, cerebellum, and mid-brain, is far greater in man than it is in the lower animals. Thus while men frequently recover from slight injuries to the cerebrum, they die from shock if the organ be extensively destroyed.

Rare cases, however, have been recorded of babies born alive and yet lacking entirely any great brain, and these have lived for a few hours, breathing, sucking, and moving about their limbs quite naturally. It is clear, then, that in man also the common reflex movements, the respiration, such automatic reactions as sucking and swallowing, and the functions of all the viscera, can continue in the absence of the cerebral hemispheres. On the other hand, all *conscious actions* depend on the function of the great brain. Conscious actions are those which are controlled by mental images or ideas.

Memory. In the untutored savage, the young child, and in all animals, any sensation that is at all intense

passes over irresistibly into action. As a result of education and experience, and in imitation of those around him, the child learns to control his impulses, and obedience takes the place of wilfulness.

A baby, when it sees a candle-flame for the first time, stretches out its hand to grasp the flame. Should it succeed, a sensation of pain follows, and this causes the baby to withdraw its fingers.

Now, the sensations of light from the flame, of burning pain, and of the movement which led to the pain, are all associated together, and are stored up in the brain as a memory. In the brain there are, as it were, reference tablets, on which are recorded the memories of past sensations and actions. We may suppose that the molecular structure of the brain is in some way altered by each experience, and that the alteration persists for a longer or shorter time according as the particular experience is powerful or weak, repeated often or seldom. Certain memories of new and startling sensations received in our childish days last our lifetime, the rest are crowded out and forgotten. To-day, we remember what we had for breakfast; a week hence, we shall probably have forgotten so trivial a matter. To remember anything, we repeat it over and over again, or try to imprint it on our brain in some startling way. As the brain is thrilled by each new sensation, mental images of past sensations, especially those which are of a similar character, or those which have been associated with the same sensation in the past, rise into consciousness. As each mental image is aroused, it may call up another, and this another, and so a train of ideas is set going. This continues until a new sensation breaks in, and, by awakening another set of memories, starts a fresh train of ideas. For example, when the author sees a certain kind of chrysanthemum, it calls up in his mind a mental image of Covent Garden. For thither

he once went as a lad at six in the morning and bought a great bunch of chrysanthemums. This experience left a lasting mental image on his brain. The mental image of Covent Garden calls up another mental image, namely, that of his lodgings whither he took the flowers; thence follows a train of ideas concerning the manner of life and companions of those days. The ideas flash with extraordinary rapidity into consciousness, but in every case it seems possible to trace how one idea leads on to another, and how each link in the chain is associated with the one that precedes it. The child's brain is receptive and retentive of the most trivial sensations. In it the book of memory is almost blank, and there is plenty of room for entries. As the book fills up, trivialities are displaced, and the vivid or constantly repeated sensations are alone retained.

Inhibition. Suppose a child for the first time sees an apple—he grasps, feels, smells, bites, and tastes it. Out of all these complex sensations there is imprinted on his brain a mental image of the shape, size, colour, smell, and taste of an apple. The next time he sees an apple, the mental image is awakened, and he strives to take and eat it. Suppose the apple belong to another, and instead of obtaining the apple he receives a push or a blow, a mental image of this painful experience will be stored up in his brain and associated with the former pleasant memory. The next time he sees an apple, the sensation may arouse two conflicting mental images, one that is pleasant and one that is painful. The one idea will impel him to take it, the other to leave it alone. The movement that follows is no longer impulsive, but one that is *deliberate*, that is, controlled by ideas. When the action which follows a sensation or idea is stopped by another sensation or idea, we speak of the process as one of

inhibition. Suppose a curious sight impel a man to cross a road. A coming cab may inhibit his movement, or else impel him to run the faster. Similarly, a man walking along may suddenly be brought to a standstill by a pain in his stomach.

The power to inhibit or restrain the motives aroused by the sensations of the moment depends on the memories of past experiences, and is the great result of education. To avoid future pain, or to gain greater pleasure, a man forgoes the desires of the moment. On this power depends the moral worth and character of a man.

Possibly the following experiment may illustrate the manner in which sensations may increase or inhibit each other. Throw half a dozen stones into a quiet pond—the wavelets set up by each interfere with one another, and a movement results which is the sum total of the whole. If the crests of two waves meet together, the one is piled on the top of the other; but if the crest of one meet the trough of another, the two waves neutralise and abolish each other. So waves of sensory impulses stream into the brain from the sense-organs; these thrill into consciousness the mental images of former sensations; all mutually affect one another, and a definite movement results from the sum total of the whole. In other words, after due deliberation, a man determines his line of action.

Regulation of the viscera. We are as a rule conscious of neither our heart-beat and respiration, nor of the regulation of the calibre of the blood-vessels, the movements of the intestines and secretions of the glands. All these functions are reflexly regulated by the central nervous system. Afferent impulses stream up from the organs to the central nervous system and excite efferent impulses, which cause the glands to secrete, the heart to beat fast or slow, the respiratory muscle to contract, &c.

For example, the presence of food in the mouth excites reflexly the flow of saliva; at the same time, the taste and feel of the food arouses in us consciousness as to its nature. The examination of the food is carried out by the aid of the higher senses and the brain, for it is of the utmost importance that hard bones or poisonous substances should not be swallowed. On the other hand, the regulation of the flow of saliva is left to the grey matter in the spinal bulb. The presence of food excites the afferent nerves in the mouth, and the impulses conducted to the spinal bulb are reflected or switched on to the efferent fibres which pass to the salivary glands. The secretion of saliva is a reflex act, and does not enter into consciousness. So is it with the secretion of the stomach, the pancreas, and the liver. The presence of food in each case excites the flow of the secretion. Each inspiratory movement excites afferent nerves in the lungs, and the impulses reaching the spinal bulb produce reflexly the movement of expiration. The expiration in its turn calls up the next inspiration. A crumb entering into the larynx calls up a fit of coughing. A dash of cold water makes us hold our breath, while a pinch of snuff or pepper causes us to sneeze. These respiratory acts are carried out by the spinal bulb.

Similarly, the heart beats more quickly when we are active, more slowly during periods of rest. The eye winks and the pupil contracts at a flash of bright light. The blood-vessels of the skin dilate and the sweat-glands pour forth sweat during hot weather, while the opposite changes occur when the weather is cold. The face from dilatation of the blood-vessels blushes when we are ashamed, or becomes pallid with fear. These changes are examples of reflex actions controlled by afferent and efferent nerves and the grey matter in the spinal bulb and spinal cord. The quality of the blood passing through

the organs also influences their activity in such a way that the blood is kept at a definite standard of purity. If the blood contain too much carbon dioxide or lack oxygen, the respiratory centre in the spinal bulb is aroused to increased activity, and the respiration deepened or quickened. If the blood be too watery, or contain too much urea, the kidneys are stimulated to excrete urine in greater abundance. If sugar be absorbed into the blood, the liver forms glycogen. All this wonderful and intricate mechanism of regulation continues, and we, so long as our organs are healthy, remain *unconscious* of their working, and even of their existence. In truth, so completely are we unconscious of the manifold processes that go on in our body, that we must laboriously seek to unravel these mysteries by the study of physiology.

Referred pains. The viscera are not sensitive to unusual stimuli like touch. The truth of this statement can be illustrated by the curious case of a bicyclist who, in falling from his bicycle, split the wall of his abdomen. He walked home unconscious of the injury, but after some time turned faint. He then found, to his great surprise, that some coils of his intestines protruded through a wound and were lying beneath his jersey. Certain conditions like over-distension or spasm of the viscera make us conscious of pain. The pain is not, however, felt in the viscera, but is, as it were, referred or reflected on to the skin. The impulses passing up from disturbed viscera to the central nervous system render it over-sensitive to impulses coming from the corresponding part of the skin. Thus the skin in certain parts becomes tender and painful. By studying the situation of the referred pain, a doctor can not only learn which organ is diseased, but by stimulating the skin with a blister he can counteract the pain and influence the diseased organ.

Emotions. It is the sum total of the sensory impulses

which stream from the viscera, the muscles, and the sense-organs that arouses in us a consciousness of general bodily comfort or discomfort. Our emotions, on the other hand, are determined by the train of ideas or mental images which are aroused by powerful sensations. Thousands of weak excitations which momentarily affect the skin, eye, ear, &c., produce scarcely any change in the tone of mental feeling. On the other hand, any powerful sensation provokes ideas which occupy the whole of consciousness. All other weaker sensations pass then unnoticed, and we are filled with an emotion of fear, love, hate, &c. The stronger the emotion, the more irresistibly are we impelled to muscular action and relieved by its expression.

A general view of the action of the nervous system. To gain a general view of the action of the nervous system, let us think of the control of the police force. Suppose a murder to have been committed in a country village; the local policeman telegraphs to the local town ordering the roads to be searched. The policeman is the tactile sense-organ, the telegraph wire is the sensory nerve, the telegraph office in the local town is the spinal cord. From this telegraph office a message is sent along another wire to the town police station, and the police are there set in motion. The police are the muscles, and the wire that sets them in motion is the motor nerve. At the same time the message is sent on to neighbouring towns and to London. That is to say, other local offices (parts of the spinal cord) and the head office (the brain) are informed of the crime or sensory impulse. The head office in London directs the operations controlling the local police offices. Attached to the head office are the cleverest detectives (higher sense-organs), and the records are kept there of past crimes, the lines of action of the police, and the success and non-success of their investigations. The

men in the head office (nerve-cells of the brain) are trained by past experiences. At the same time they are kept well informed of present conditions by messages from the detectives and the local offices. Combining all these sources of information, the men in the head office control the search for the murderer. When any crime of an unimportant or ordinary character is committed, the local office carries out the appropriate line of action, and the head office is not informed of the fact. But on all extraordinary matters the head office is consulted, and, by the light of experience and the inquiry of detectives, decides the course of action. So is it with the brain and spinal cord. The brain has attached to it the cleverest detectives —the eye and ear, the smell and taste organs. In all important and unusual matters the brain and higher senses are called into play, and the former decides the line of action of the muscles, while acts which have become habitual and usual are carried out reflexly in response to sensory impulses by the spinal bulb and spinal cord, and do not enter into consciousness.

Conscious actions become automatic. Every skilled movement, such as walking, dancing, swimming, skating, bicycling, and trade handiwork, we at first learn by conscious effort. But there is no movement of the body, however difficult, which we cannot, by continual practice and repetition, reduce to a mechanical certainty so complete that it will be performed, without any intention on our part, as the necessary reaction to certain sensory stimulations. Every preceding movement automatically arouses the next one in the performance of the complex action, just as one respiration arouses the next. 'Practice maketh perfect,' and when the perfection is attained we have but to start the movement, and it will be carried out through all its phases without any effort on our part. Suppose we

start walking, the sensations arising from one step call up the next, and we continue to walk with our mind engaged on other matters until some other sensation inhibits or arrests our steps. Most of us, in learning the piano, cannot move the fourth finger without moving one of the others at the same time. It is an effort to try and do so, for the fingers habitually move together in grasping objects. By practice we can force this finger to move while we inhibit the movement of the others; the effort becomes less and less as our purpose is more perfectly attained. In such case we must be forcing the nervous impulse to pass to certain muscles, and inhibiting its passage to other muscles. It would appear as if, by repeated experiences, tracts and pathways must be beaten through the nervous system. There is evidence to show that the axons become covered with a medullated coat as each new tract is formed. Thus the structure, like the habit, becomes fixed.

During the growth of the child's brain these pathways are beaten out by practice, and the child becomes drilled in habits and skilled in complex movements. Think of the thousands of sensations that stream into the child's brain day by day. These evoke movements, some of which lead to the attainment of the desires of the child, others lead to falls and tumbles, reprimands and punishments. As the child becomes educated, all its movements become controlled. Movements of the wrong kind are inhibited by mental images of former pain. Particular sensations now produce definite lines of action, by which the end in view, excited by the sensations of the moment, is attained, and this without pain and with as little trouble as possible. Not only combinations of movements, but trains of ideas, are rendered stable by repetition. In other words, the character of a man is formed by education. The longer a man has indulged in certain habits, the more difficult it is to break the association, and after he has

B b 2

reached a certain age it is almost impossible to beat new pathways through the nervous system. The older a man grows, the more rooted in habits and ideas he becomes. Thus the task of breaking a man of evil life or drink becomes, after a certain age, more and more hopeless. When by education the inhibition of all impulsive movements has become habitual, the tendency for any powerful sensation to pass over into movement is shown by the change of facial expression. The most controlled of us cannot conceal the movements of the facial muscles under the influence of strong emotions. Thus we read what is passing in a man's mind, and tell his character by the lines of his face. To read character from the lines on the hand and the bumps on the head is impossible. Palmistry and phrenology are other names for quackery and deceit. The lines of the hand are folds produced in the same way as the creases at the elbow of a man's coat. The bumps on the head are in many places due to air-spaces in the bone or thickenings of the bone, and by no means represent swellings of the brain substance.

CHAPTER XXXI

THE NERVOUS SYSTEM (*continued*).

Speech. In learning to talk a child sees an object—say a dog—and hears its name. The sound 'dog' is imprinted on the brain as a word-memory. By repetition the imprint is rendered permanent. The child strives to control the speech-muscles so as to reproduce the sound.

When by practice the sound 'dog' has been attained, an idea is stirred up in the brain of the right degree of muscular movement necessary to produce the sound in question. Thus the child day by day stores up word-memories, each of which signifies some object, or the quality and characteristics of some object, in the world around him. Each word-memory is linked up in the brain with the sight, touch, taste, and smell memories derived from the examination of the particular object represented by the word. Each word-memory is likewise linked up with the memory of how to use the speech-muscles so as to speak it. As the child becomes older he learns to read and write. He hears the word 'dog' spoken, and sees certain letters that represent the word when written. By constant repetition a sight-memory of the written word is imprinted on his brain, and this is linked together with the sound-memory of the spoken

word. Now the sound-memory has been already linked, not only with the muscular memory of how to speak the word, but also with the touch, look, bark, &c., of the object which the word 'dog' represents. Thus the child learns to read 'dog,' and the word he reads calls up the complete mental image of the object represented by the word.

Connection of mind and body. It is most important to bear in mind that mental processes and bodily functions are interwoven one with another.

The state of emotion alters the pulse-rate. The face

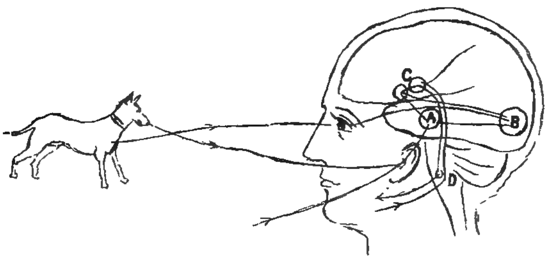


FIG. 144. A. Auditory centre. B. Visual centre. C. Speech centre. D. Motor cells of speech-nerves in the spinal bulb. Sight of dog, bark of dog, word 'dog' and sensations from speech-muscles are represented by arrows passing into the brain. The centres are connected by association fibres.

blushes with shame owing to dilatation of the blood-vessels. We feel our hearts throb during periods of emotional excitement. The lachrymal gland is excited by painful emotions, and tears flow. Emotions of joy make our steps light and every movement easy and prompt, while the man suffering from depression moves his limbs slowly and heavily. If a man clenches his fists and sets his face-muscles in the position expressive of anger, an emotion of wrath may irresistibly steal over him, and his voice sound forth tones of anger. The movements of the muscles associated with anger call up the emotion, just as the emotion usually produces the movements.

Mental activity depends upon the proper action of the senses, of the brain, and ultimately of the whole body. The starving man, and he who is stricken with fever, suffer from hallucinations; ideas then run riot in the brain, and are no longer controlled in orderly sequence. It is as if barriers set up by habit were broken down, owing to the deficient nutrition of the brain, and the sensations, by streaming out of the beaten tracks, marshalled together a disorderly and disjointed set of ideas. Similarly, when a man is poisoned by the drug strychnine, a mere touch will arouse a general spasm of the body. The sensation, no longer confined to one pathway, spreads throughout the nervous system and arouses all the muscles into activity.

The Greeks and Romans were well aware that a vigorous mind depends upon a vigorous body. *Mens sana in corpore sano.* The old Latin proverb expresses a truth that has been too often lost sight of in later days. By the increased vigour of the circulation during muscular exercise, and the removal of clogging waste products and surplus food, the brain is refreshed. Gladstone owed his mental vigour, not only to his studies of men and books, but also to the axe which he wielded in the park of Hawarden.

Like all other organs, the brain degenerates if not excited by fresh sensations. All that we have mastered by practice comes to be executed reflexly and without mental effort. To grow in mental power and enjoy the full consciousness of life, we must ever seek 'fresh fields and pastures new,' conquer new worlds of knowledge, and gain still other movements of skill. Thus for men employed daily on some special piece of work requiring, when once skill is acquired, little mental activity, a hobby is necessary to render their leisure time happy. The man consumed with the desire to follow some new and favourite

hobby has no time to become depressed. Hysteria and nervous exhaustion are the fruits not of overwork, but of lack of varied interests and employment. The common opinion that handwork is menial and low leads to most pernicious consequences. The girl who, turning from brain-work to manual labour, can cook, scrub, wash, and garden invites the bloom of health to her cheeks; while the fine do-nothing lady loses her good looks, suffers from the vapours, and is a nuisance to her friends and a misery to herself.

The sensations of the present, and the ideas they call up, vary with every change in our external surroundings. Hence the relief obtained by frequent changes from business to recreation, from one subject of study to another, and the value of travel and change of scene.

The intensity of the stimulations required to keep the brain in active health must be regulated by the capacity of the individual, and this, as teachers must remember, varies enormously. Exhaustive stimuli produce pain, moderate and suitable ones pleasure. According to the varying condition of the brain, its vigour or fatigue, its supply of good or bad blood, our ideas run easily or slowly, and our memories are weak or strong.

Each individual brings with him the germ of his future character. He is endowed from birth with greater or less mental capacity. One man may be able to discriminate a hundred different shades of colour between scarlet and yellow, another but five shades. Some can discriminate the slightest variation of pitch in a musical tone, and another be incapable of appreciating any difference between two notes widely separated on the musical scale. The inborn power of discrimination varies widely, and this alone produces great variations in the intellectual capacity of individuals.

Many of the actions of man are instinctive. He is born

to an inheritance, for his body and brain have been moulded by the experiences of past generations; he must therefore follow a certain line of life. Man, in common with animals, builds a house, weds a mate, and nurtures his children. But in contrast to animals, he possesses infinitely greater power of learning and acquiring skill by experience. It is by education and the influences that surround him that the plastic brain of the child is moulded for good or evil.

Sleep. At periodic intervals of time the brain and the body require rest, and we fall asleep. All the functions are lowered during sleep. The heart beats more slowly, the respiration is less rapid, while the skeletal muscles are relaxed. The production of heat in the body is reduced, and thus we seek sleep in a warm place. Owing to the cessation of muscular movement, and the lessened formation of heat, much less carbon dioxide is expired during sleep. Led by feelings of fatigue, we seek a quiet place free from all stimulations of light, noise, or cold, and so soon as sensations cease to enter into consciousness, we fall asleep.

Sleep is as necessary as food. An animal or man is killed by being kept awake for a few days. Sleeplessness leads to disturbance of the brain's functions, and sensations then give rise to hallucinations or false mental images. Men, when greatly fatigued, can fall asleep, and yet reflex movements may continue, such as walking, riding, &c. Post-boys have fallen asleep on their horses, soldiers during a battle. The story is told of the captain of a ship who fell asleep by the side of a cannon while the battle proceeded. Men vary greatly in the amount of sleep required. Young babies sleep most of the day; children require twelve hours', young adults eight hours' sleep. In old age five or six hours' sleep is sufficient.

Napoleon slept but four hours a day. Many men—for example, the Red Indians—possess the power of falling asleep at any moment and in any place, like a cat.

During sleep, consciousness is alone in abeyance. The sense-organs and nerves are in action. The rattle of a cart will quicken the pulse of a sleeper without arousing him. Gently tickling the face, or the laying of a cloth on the mouth, will provoke reflex movements of such a character as to remove the cause of offence, and yet the sleeper remain entirely unconscious. During the first hour or two of sleep it takes a much louder sound to awaken a man than in the later hours. Sleep is deepest about the second hour.

Dreams. When consciousness is partly awake and partly sleeping, we have the condition of dreaming. In dreams, trains of ideas are started by some external sensation, but are not controlled by the higher senses. Thus they run a fantastic course. The rapidity with which ideas flash into consciousness is shown by the fact that we may dream through a long adventure and awake to find we have scarcely slept one minute.

In somnambulism, the dreamer may talk or walk as he dreams. The balance of the movements is maintained reflexly, just as it is when a man is conscious. The sleep-walker may cross dangerous ledges and climb roofs; he walks steadily, for he is not conscious of risk. All stories of higher intellectual powers being evidenced during sleep may be taken as false. Fantastic and strangely associated ideas, not the solving of difficult problems, occur during dreams. The writer of fiction, and not the thinker, can make use of his dreams. When properly investigated it is found that neither sleep-talkers, nor men in delirium of fever, ever exhibit intellectual power of so high an order as when they are fully conscious. The poet

Coleridge for a long time hocussed the world with a story of a servant girl who, while in a delirium, talked Latin, Greek, and Hebrew. These languages she was supposed to have unconsciously learnt from her master, a great scholar, who indulged in the habit of reading aloud. The whole story was a mischievous invention of Coleridge's.

After epileptic fits, impulsive acts resembling dreams are often performed, the higher consciousness being then in a state of abeyance. For example, a man, after a fit, impulsively jumped into a cart and drove two miles into the country. He was arrested for stealing the horse and cart, and could offer no explanation of his conduct. The absent-minded man may be so occupied by one train of ideas as to ignore all other sensations. The author occasionally finds, when he has gone to dress for dinner, that he has undressed himself as if he were going to bed. Such habitual automatic acts as undressing, when once started, are carried to their termination if consciousness be dreaming over some mental problem.

Mesmerism or hypnotism. If a hen be laid on the floor and held for a moment in a strange position, it will, if the hands be gently removed, continue to lie motionless. So a frog or a snake can be rendered motionless by holding it in one position or stroking the back of its head. Any strange sensation which is utterly beyond our experience, and from which we know not how to escape, inhibits all power of action. A man may be rooted to the ground and struck dumb with terror.

Our actions are largely controlled by the suggestions or advice of our fellow men. A strong man can, by suggestion and command, gain complete mastery over a weak man. The hypnotic condition is similar to the helpless state produced by terror. He who is hypnotised loses power of deliberation, and automatically obeys the suggestions of

the hypnotiser. The hypnotic condition is promoted by making mysterious passes with the hands over the face of the subject, and by setting him to gaze at some bright object, and so weary the eyes. In order to produce the hypnotic condition it is necessary that the subject should believe in the power of the hypnotiser. When the hypnotic condition is established, the subject will obey the suggestions of the hypnotiser, and at his command carry out automatic movements. The subject will not, however, obey any startling suggestion that is contrary to his moral character. Just as the hypnotised hen or frog starts

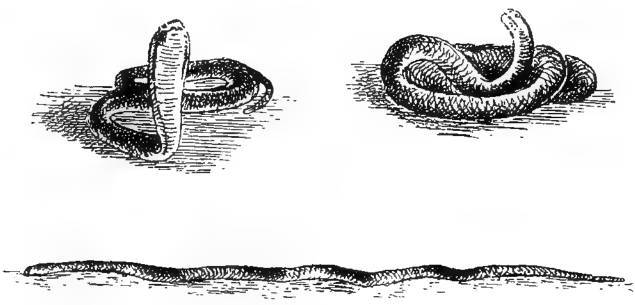


FIG. 145. Cobra hypnotised by stroking and made stiff and straight.

up on receiving any powerful sensation, so the subject will be aroused from the hypnotic condition. Thus men cannot be made to commit unnatural crimes by hypnotic suggestion.

Since it is unwise to render one mind too dependent on others, hypnotism must be regarded as dangerous, in so far as it weakens the responsibility of the individual.

The whole subject of hypnotism is surrounded with charlatanry, quackery, and lies. It is one of the weapons used by clever rogues to frighten and impose upon the weak and foolish. Spiritualism is another of their weapons.

No spiritualist has ever successfully withstood the exact tests of scientific investigation. The tricks of spiritualistic mediums have never equalled in mystery those of the best conjurers, and much in their behaviour that is astonishing to the layman is recognised by the student of nervous disease to be symptoms of hysteria.

How little truth there is in thought-reading is shown by the fact that thought-readers can never use their supposed powers so as to obtain wealth or reap any material advantage.

Man naturally notices coincidences and forgets discrepancies. He is superstitious, and, when out of health, suffers from hallucinations; he draws wrong conclusions from imperfectly perceived sensations. Thus ghosts and witches, spiritualism and many other -isms, trouble his brain, and he is easily deceived and fleeced by clever rogues.

Localisation of Function in the Brain.

The motor area. Among the wounded soldiers brought to the German surgeons at the time of the Franco-German War was one whose skull had been partly torn away. His brain lay exposed. The surgeons employed an electric current to test whether the nerves of his face were paralysed. They found to their astonishment that, whenever the electric current was applied to the wounded side of the head, certain movements were excited. The man's muscles twitched on the opposite side of his body. Following up this observation, it was quickly determined that movements on the opposite side of the body can be excited whenever a certain area of the cerebral cortex is electrically excited. The area in question lies beneath the parietal bone, stretching from the top of the brain to the level of the ear.

Excitation of different spots in this region of the cortex provokes different movements (see Fig. 138). Thus stimulation of the lowest part produces movement of the face; of the middle, the arm; and of the uppermost, the leg. The movements in every case take place on the side of the body which is opposite the excited hemisphere. The cortex in this region is like the key-board of a piano, and different groups of muscles can be excited at the will of the experimenter by shifting the position of the electrodes.

On stimulation of the *motor area* a man feels nothing but the movements of his muscles. This observation is of great interest, for it shows that sensations coming from the sense-organs alone enter into consciousness. When a motor impulse is discharged from the brain, we are conscious, not of the actual discharge, but of the movement of the muscles. Irritation of this motor area by tumours or inflammation is one of the causes of epileptic fits.

The pyramidal tract. From the cells which lie in the motor area there passes off a most important set of axons, called the *pyramidal tract.* These run down the stem of the brain, and after crossing over in the spinal bulb, course down the spinal cord. The axons end by branching round the motor cells in the anterior horn of the spinal cord. It is through this pathway that the brain controls the movements of the muscles. Owing to the crossing of the fibres, the right side of the body is controlled by the left cerebral hemisphere, and the left side by the right. The sensory fibres, which enter from the posterior roots of the nerves and run up in the spinal cord, also cross over when they reach the spinal bulb. Thus, those from the left side of the body pass to the right cerebral hemisphere, while those from the right side of the body pass to the left cerebral hemisphere. So is it with the nerves from the

eye and ear. Each hemisphere is thus bound up with the opposite side of the body, both as regards feeling and movement.

When the left motor area is damaged, paralysis results on the right side of the body; and when the right motor area is injured, paralysis results on the left side. If the paralysis result from injury in a young animal, other pathways are formed in the brain, and recovery takes place. The older a man is, the less fully he recovers from a stroke of paralysis. The commonest cause of a stroke is bursting of one of the blood-vessels which supply the cerebrum.

The areas connected with speech and the special senses. When the lowest part of the motor area on the *left* side is destroyed, the power of speech becomes paralysed. A man thus afflicted can understand words and make noises, but he is quite unable to control the muscles so as to speak. In all right-handed people the speech area is situated on the left side of the brain, but, curiously enough, in left-handed people it is situated on the right side.

When another region of the cerebral hemisphere is destroyed, namely, the temporal part that lies beneath the skull behind the ear, a loss of the memory of words may follow. A man whose brain is thus damaged cannot understand words. If he tries to speak, his words are strung together without sense or meaning. This part of the brain is supposed to be especially associated with the sense of hearing. If the hind part of the cerebral hemisphere be destroyed, a man can no longer see objects in the opposite side of the field of vision. That is to say, after destruction of the hind part of the left hemisphere a man will, when looking straight in front of his nose, be unable to see anything on his right side.

The part of the brain especially connected with the

sense of smell lies at the base of the cerebral hemisphere and towards the front, where the olfactory nerves enter. If this part be jarred against the bony floor of the cranium, as it may be by a violent blow on the head, a man may lose his sense of smell.

From the facts stated above, it is clear that certain parts of the brain are more or less closely connected with certain functions. The optic nerve-fibres stream to the grey matter in one part of the cerebrum, the auditory fibres pass to another part, the olfactory fibres to a third; the fibres ascending from the spinal cord and bringing sensations from the skin and muscles pass to yet another part, and from this last part there arise the fibres of the pyramidal tract, which course down the spinal cord and control the muscles. All these parts of the brain are by no means sharply separated, but rather are closely knit together by an incredible number of association fibres.

Functions of the mid-brain and spinal bulb. Very little is known of the functions of the masses of grey matter that lie at the base of the cerebrum. The optic nerves enter into the mid-brain, and many of the fibres form connections with the grey matter both in the corpora quadrigemina and in the cerebellum, while the rest pass on to the cerebral hemispheres. The axons which control the movements of the eyes issue from the cells in the grey matter of the mid-brain. The corpora quadrigemina are large in the lower animals, such as the pigeon and frog. These animals can see after removal of the cerebrum. With the existence of the grey matter in the spinal bulb there is bound up the reflex control of respiration, the frequency of the heart-beat, the tone of the blood-vessels, the mechanism of swallowing, the secretion of saliva. Most important nerves are connected with the spinal bulb,

and injury to this part produces immediate death, owing to the cessation of respiration.

Functions of the cerebellum. Many of the fibres which ascend in the spinal cord turn off as they pass up the stem of the brain and reach the cerebellum. These end in the grey matter of the cerebellum; other fibres pass out of the cerebellum and connect this organ with the grey matter of the spinal bulb, the mid-brain, and the cerebrum. The fibres entering and leaving the cerebellum compose the three pairs of cerebellar peduncles. If one cerebral hemisphere be destroyed in a young animal, the opposite half of the cerebellum ceases to grow. There is a *crossed connection* between the cerebrum and cerebellum. The right half of the cerebellum is connected with the left cerebral hemisphere, while the right cerebral hemisphere is connected with the left half of the cerebellum. Many of the fibres of the cranial nerves pass to the cerebellum and particularly fibres in the auditory nerves, which come from the semicircular canals.

Electrical excitation of the cerebellum causes movements of the head and eyes. If a strong electrical current be passed through the head of a man below the occiput and in the region of the cerebellum, he feels constrained to tumble over to one side. The destruction of the whole cerebellum in an animal does not produce death, that is to say, so long as the spinal bulb which lies in front is not injured. After the loss of this organ an animal becomes weak and unsteady in its movements. Its motions are awkward, and no longer delicately balanced. Disease of the cerebellum in man leads to dizziness and a reeling gait like that of a drunken man. It is said that the particular function of the cerebellum is to aid the cerebrum in the control of the muscles. By its means the actions of the muscles are so balanced that the body and limbs

are poised in the right positions during the execution of movements.

The orderly execution of muscular movements. The balanced movements of the muscles are controlled by sensory impulses passing from the tactile organs, from the sensory nerve-endings in the muscles and joints, from the eyes and semicircular canals.

A baby sees an apple and stretches out its hand to grasp it. When it feels the apple, this sensation excites the fingers to close upon it. The hand is guided to the apple by the eye; the sensory nerves of the muscles and joints convey impulses to the brain, whereby the child feels the position of its limb and can estimate the amount of weight lifted or the pull of the muscles. The right amount of movement to gain any desired end is only acquired by practice. The child attempts various degrees of movement, and, by means of the sensations that follow, learns whether the movement is successful or not.

The following experiments show how the movements are guided by sensations. A man can walk blindfolded, but if the soles of his feet be frozen and rendered devoid of feeling, he can no longer do so. A brainless frog ceases to maintain the sitting position so soon as the skin is removed from its legs. The sensations streaming up from the skin in contact with the ground provoke the action of the muscles which maintain the balance of the body. If all the posterior roots coming from the arm of a monkey be cut, the animal will no longer feel the limb, and will, in consequence, cease to move it.

Forced movements. If the peduncles of the cerebellum or mid-brain be suddenly damaged on one side, what are termed 'forced movements' result. Rabbits thus damaged by shot may turn a succession of somersaults or run round

in a circle like a circus horse. In such case one side of the brain, owing to the irritation, receives different sensations from the other side, and the muscles on the two sides of the body are excited to act unequally.

General spasms of the whole body are produced by suddenly depriving the brain of oxygenated blood. These spasms are the cause of 'towering' in birds. A bird, when shot in the lungs, may shoot up and up into the sky and then fall from a great height like a stone.

CHAPTER XXXII

THE SENSES: TASTE, SMELL, AND TOUCH.

Sensation. At every moment of our life waves of energy are sweeping against our bodies. Energy of light, sound, heat, the pressure and contact, the smell and taste of matter excite the different sense-organs, each of which is fitted to transform one or other kind of energy into nerve impulses. The eye is sensitive to light, the ear to sound, the nerve-ending of the skin to pressure and temperature, the nose to smell, and the tongue to taste. Each sense-organ possesses its own peculiar and individual structure, by which it is rendered sensitive to one or other form of energy. Thus the eye cannot hear, and neither can the ear see nor feel. The sense-organs consist of special kinds of cells. In the sense-organs of taste, smell, sight, and hearing, the cells are provided with hair or rod-like processes. In contact with the sense-cells there lie the branches of afferent nerve-fibres.

So soon as a sense-organ is stimulated by a form of energy to which it is susceptible, it converts this energy into nerve impulses, and these latter are conducted by the nerve-fibres to the central nervous system. The nerves of sight enter one part of the brain, the nerves of hearing another part, and these parts are, from birth onwards, educated to receive impulses from the eye and ear

respectively. Every impulse that streams into the brain from the nerves of sight awakens consciousness of light, and of light only. Similarly, every impulse that enters by the nerves of hearing arouses consciousness of sound, and only of sound; and so it is with the other senses. The story is told of a man who stated to the judge that he recognised his assailant on a dark night by the flash of light which occurred at the moment when he received a blow in the eye.

Place your finger against the ball of one eye, and you will see curious coloured patterns. The sensory apparatus of the eye is here excited by pressure, but the brain becomes conscious not of pressure, but of light.

Noises in the head may be produced by passing a galvanic current through the skull. Each pole being pressed upon the bony case of the internal ear.

Intensity and quality of sensation. Every sensation possesses a certain *intensity* and a certain *quality*. If you strike the same musical note at first softly, and then strongly, the intensity changes, but the quality remains the same, while on softly sounding two or three different notes, the quality changes, but not the intensity. Lemonade may taste sweet or sour—this is a difference in quality. Sweet lemonade may taste slightly or very sweet—here we are dealing with a difference in intensity. The brightness of a light depends on its intensity, while its quality is determined by its colour.

Beside the quality and intensity, we judge the *space* of a sensation, and detect the *time* each sense stimulus lasts. Sensations, moreover, are accompanied by a *tone of feeling*, pleasure, pain, or indifference. They form the elements out of which all mental processes spring.

We can study the structure of the sense-organs and

conceive the mechanism by which a wave of energy is changed into an afferent nervous impulse; we can follow an impulse along the nerve into the brain and observe its effect on a fellow being. But a great gulf is fixed between the tracing of the impulse thus far and its rise into consciousness. How does a sensation leave its imprint as a memory, and what is consciousness? These questions cannot be answered. The study of the brain gives us no shadow of indication as to how our mental life comes into being. Although the sensations result from a change in the brain, yet we do not place the sensations there, but always refer them to something outside us. If you hear a knock on the door, you refer the sound to the door. A touch sensation is referred to the part of the skin that is touched. We project all our distinct visual sensations into space.

Fusion of sensations. When any sense-organ is excited by a rapid succession of stimuli, the latter are not perceived as separate sensations, but are fused together into one continuous sensation.

Whirl a piece of string, alight at one end, round and round—a complete circle of fire is perceived. A catherine-wheel produces the same effect, while the pattern on a coloured top forms rings of colour when the top is set spinning.

These effects are due to the fact that a sensation lasts longer than the stimulus which produces it. If, before one sensation is over, the next be upon us, fusion takes place, and a continuous sensation is produced. If a continual uniform stimulus be kept up on any sense-organ, the sensation is, after a time, no longer perceived. On entering a sewer the stench is at first overpowering, but after a short period it is no longer noticed. A continuous sound, like the fall of a fountain, the rumble of carts in the street, the sound of a train in

motion, becomes after a time almost inaudible. So soon, however, as a stimulus alters in intensity or quality it is once more perceived. Any sensation that is extraordinary or out of the routine most forcibly strikes our attention.

An important point in regard to the senses is their capacity for education. The touch can be so trained in the blind that they can read by the aid of raised letters. The trained eye of an artist can see a hundred or more different tones in a piece of rock which to another man looks uniformly grey. A tea or wine taster can, in a marvellous manner, detect differences in bouquet, and price samples; while the conductor of an orchestra can pick out from a hundred instruments the one that played a wrong note. It is not the sense-*organs* that become educated, but the power of the brain to perceive and discriminate.

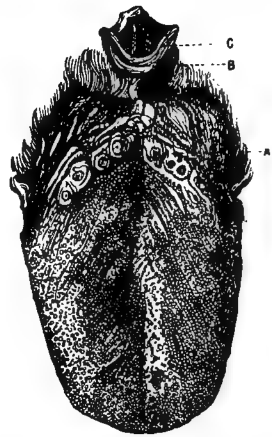


FIG. 146. Tongue, epiglottis, and opening into larynx. A. Circumvallate papillae. B. Epiglottis. C. Vocal cords.

Taste. The tongue is covered with little processes or papillae formed of horny cells. Some of the papillae are long and slender, others are shaped like a puff-ball fungus. At the back of the tongue there are a few large papillae, each of which is surrounded by a groove or trench. These are called the *circumvallate papillae*, for they resemble the shape of a mound encircled by a moat.

At the sides of many of the fungiform papillae, and of all the circumvallate papillae, the cells are modified to form *taste-buds*. Each taste-bud consists of a cluster of

cells arranged somewhat like the petals of a poppy-bud. The sense-cells in the centre of the bud have slender hair-like processes. These processes project out into the trench surrounding the papillae, and so are exposed to the juices in the mouth. Fibres of the glosso-pharyngeal nerve end by branching among the sense-cells within the taste-buds. Similar taste-buds are scattered over the surfaces of the soft palate and the epiglottis. A branch of the fifth cranial

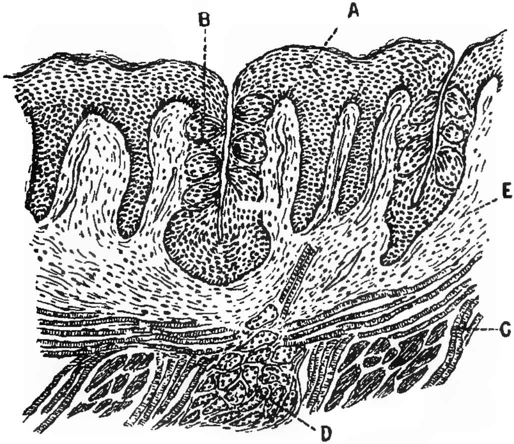


FIG. 147. Microscope, low power. Section through fragment of tongue. A. Stratified layers of cells. B. Taste-buds. C. Striated muscle-fibres. D. Mucous gland. E. Soft, vascular connective-tissue layer.

nerve supplies the front part of the tongue, and is also concerned with taste. The sensations which we commonly call taste are very complex; they are in fact compounded of sensations of touch, smell, and taste.

By the sense of taste, properly so called, we can detect four qualities only, namely, sweet, bitter, sour, and salt. It is by the sense of smell that we detect the flavours of food and drink. The vapours or small particles of the food pass from the back of the mouth into the pharynx, and thence into the nose, where they are smelt.

Hold your nose, and bite first an apple and then an onion. You can scarcely detect any difference, for the flavour of an onion depends upon its odorous particles, which are wafted by currents of air from the pharynx into the nose.

A man suffering from a heavy cold in the nose cannot enjoy the flavour of wine or tobacco. Sensations of pungency, and the smarting or burning, gritty or smooth qualities in the food, are detected by the tactile nerve-endings in the tongue. Our likes and dislikes are largely determined by these touch qualities.

The sense-cells in the taste-buds are excited by the molecular vibration of substances brought into a state of solution. A powder will not be tasted until it be dissolved. A vapour such as chloroform tastes sweet but probably it is dissolved in the saliva before it is tasted.

Wash out the mouth with water, and then place a few grains of powdered sugar on the tip of the tongue. No sensation of taste will arise until the sugar is dissolved. With a brush dipped in a solution of sugar, paint first the tip and then the back of the tongue. The tip is the more sensitive part to sweets. Repeat the experiment with a bitter, such as a solution of quinine. The back of the tongue is more sensitive to bitters.

Obtain from the chemist a gramme of saccharine (an excessively sweet substance). Dissolve it in 100 cubic centimetres of water = 1 part in 100. Take one cubic centimetre of this solution and add it to 99 cubic centimetres of water = 1 part of saccharine in 10,000 water. Take one cubic centimetre of this second solution and add it to 9 centimetres of water = 1 part of saccharine in 100,000 water. Taste this—you may still detect sweetness. This experiment shows the delicacy of the sense of taste.

We can just detect

1 part of sugar		dissolved in		83	parts water.		Sweet.
1	,,	quinine	,,	,,	33,000	,,	,,	Bitter.
1	,,	saccharine	,,	,,	200,000	,,	,,	Sweet.
1	,,	strychnine	,,	,,	2,000,000	,,	,,	Bitter.

By means of the sense of taste we cannot accurately detect poisonous from edible substances. For example, all kinds of chemical acids produce but one sensation of acid. The sensation may be more or less intense, but does not vary in quality. Similarly, a solution of quinine (1 part in 10,000 water) cannot be distinguished by taste from a solution of morphine (1 part in 3000 water). Both are equally bitter.

Smell. The chambers of the nose are separated from each other by a partition. They communicate with the cavity of the pharynx. The floor of the nose is formed by the hard palate; the roof by the ethmoid bone. The latter is pierced by a number of small holes, through which the olfactory nerves pass from the brain. At the sides of the nose there project the upper, middle, and lower *turbinate* or scroll-like bones. The whole of the surface is covered with a soft, vascular mucous membrane, in which there lie many small mucous glands.

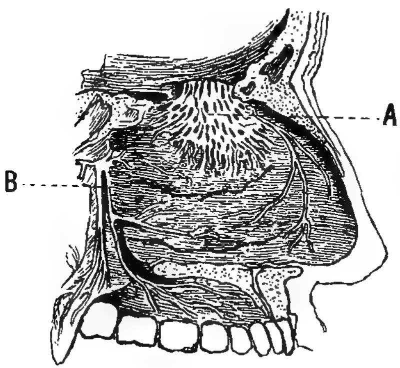


FIG. 148. Section through the nose. A. Olfactory nerve-fibres. B. Branches of the fifth nerve.

By obtaining half a sheep's head from the butcher you can learn at a glance the main features of the structure of the nose.

The mucous membrane lining the lower part of the nose is covered with a ciliated epithelium similar to that found in the respiratory passages. Through this part of the

nose we breathe. The mucous membrane is here supplied by branches of the fifth cranial nerve, and the nerve-endings are excited by any pungent or irritating vapour. The upper part of the nose is supplied by the olfactory nerves, and is sensitive to smell. The cells lining this part of the nose are several layers thick, and do not bear cilia. Some of the cells are long and columnar in shape, while others have slender hair-like processes. The branches of the olfactory nerve-fibres are continuous with the latter cells. By the movement of sniffing, air is drawn into the upper part of the nose, and thus the olfactory sense-cells are excited.

The olfactory sense-cells are excited by the molecular vibration of matter in a state of vapour. A grain of musk retains its scent for years, and yet does not appreciably alter in weight. If one-thousandth part of a gramme of an evil-smelling substance called mercaptan be divided into four hundred million parts, we can smell one of these infinitesimally small parts. The scent of flowers and the stench of putrefaction are due to vapours of chemical substances. It is only by certain molecules that the olfactory sense-cells are excited, and thus many substances have no smell. Our like or dislike of a smell depends very much on its intensity. Many vapours, which produce a pleasant perfume when freely diluted with air, become an unbearable stench when too highly concentrated. Smells vary greatly in the rapidity with which they diffuse through the air. You know how the heavy scent of tobacco flowers hangs about a garden on a still night. Smells are absorbed by certain substances, such as wool, lard, blotting-paper. The smell of tobacco clings to woollen curtains, while hay soaked in water absorbs the smell of paint.

To excite the sense of smell, the vapour must be in rapid motion. Breathe in and out deeply several times so that you can hold your breath a long time, then hold it and unstopper a bottle of ammonia, just under the nostrils. A tingling sensation results, owing to the excitation of the ordinary nerves of tactile sensibility. Pinch

the nose to imprison some of the vapour and walk out of the room. Now breathe through the nose. The 'smell' of ammonia can be detected at once. Repeat the experiment with oil of cloves.

In many animals the sense of smell is far more highly developed than in man. For example, dog-fish find their prey by the sense of smell rather than by sight. Hounds similarly track the scent of the fox or stag. The Australian natives, on the other hand, track the spoor of an animal by the sense of sight. In man the visual sense has been perfected to the highest degree, and the sense of smell has fallen into corresponding neglect.

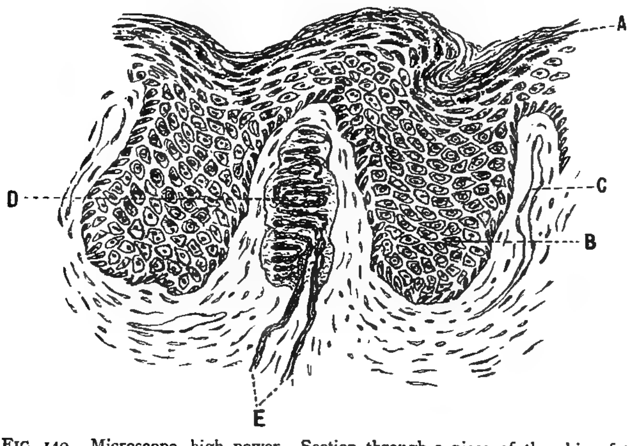


FIG. 149. Microscope, high power. Section through a piece of the skin of the finger. A. Epidermis: horny cells. B. Soft growing cells. C. Capillary in a papilla of the connective-tissue layer or dermis. D. Touch corpuscle. E. Nerve-fibres.

We store up comparatively few mental images of smell, and thus those imprinted during childhood generally persist. A scent may suddenly awaken a most vivid mental image of some place we visited long ago as a child.

Touch. In the papillae of the skin there lie, beneath the epidermis, small oval bodies known as touch corpuscles. These consist of a dense mass of connective tissue. A

nerve-fibre winds round each corpuscle and ends within it. Lying here and there in the subcutaneous fat of the hand and foot may be found other larger corpuscles. These are composed of a number of connective-tissue coats arranged concentrically, like the layers of an onion. A soft protoplasmic core occupies the centre of these large corpuscles, and a nerve-fibre ends in the core. The corpuscles seem to be so constructed that the nerve lying within may be compressed, and thus stimulated, by the impact of any substance against the skin. Some of the nerve-fibres end in the epidermis of the skin by branching among the cells.

The skin is sensitive to the impact and pressure of substances, to heat and cold, and to powerful chemical irritants.

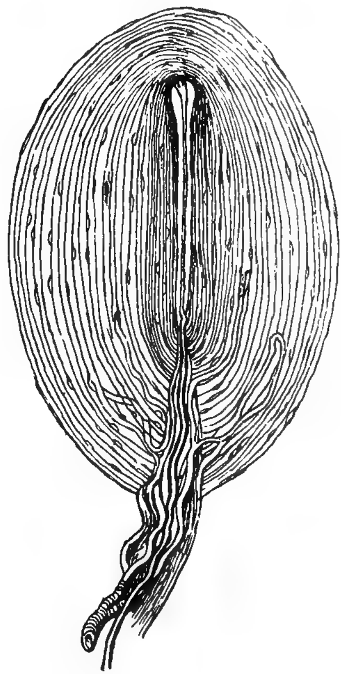


FIG. 150. Microscope, high power. Section through a large touch corpuscle. A nerve-fibre ends in the central core, and this is surrounded by concentric connective-tissue coats.

Lay a weight on your hand, and notice that the sensation of pressure rapidly dwindles away. Steady pressure arouses but a weak sensation.

Even when the hand is supposed to be at rest, the arteries underneath the skin are throbbing and lifting the skin against the weight. The muscles, moreover,

cannot be kept absolutely quiet, and thus the hand trembles slightly. Sensations of steady pressure are no doubt due to the impacts of the skin against the weight.

The sensitiveness of the skin to impact varies in different parts of the body. Make comparative measurements by dropping little pieces of elder-pith or blotting-paper from a height of one foot on to the skin of a friend. Investigate the forehead, the arm, the palm, and the back of the neck. The forehead will be found to be most sensitive. Find the smallest piece of pith which will produce a sensation of impact there. A heavier piece will have to be taken to excite the palm, or the skin at the back of the neck.

Every touch sensation bears what is termed a *local sign.* If the same piece of elder-pith be used as a stimulus, the quality of the sensation derived from its impact will vary in different parts of the skin. Although the stimulus be the same, the sensation is not. By the quality we recognise whether it is our forehead, arm, neck, or foot that is touched. The local sign probably depends on the presence or absence of hairs, the thinness or thickness of the epidermis, or other slight differences in the structure of the skin. If the foot be touched the particular quality of the sensation immediately arouses the idea foot, while if the hand be touched the quality is different, and there enters into consciousness a mental image of the hand.

The child learns to associate a certain quality in the tactile sensations with certain parts of the skin. For example, it touches an object with its fingers, and feels a touch sensation of a certain quality. At the same time it may either move its fingers and notice that the sensation alters, or else observe the object with its eyes and see where the latter comes in contact with its skin. By such means it comes to associate a particular quality of sensation with the fingers. Our powers to localise skin sensation exactly varies in different parts of the body, for it depends on practice.

Shut your eyes and ask another to touch one of your fingers. You can at once indicate the finger which has been touched. Let him, however, touch the second, third, or fourth toe, and you

will probably not be able to localise the touch correctly. Cross the ring and middle fingers and you will find localisation much more uncertain.

These three toes are usually moved so as to feel and examine objects together, and not separately. The toes are also concealed from sight, therefore the brain has not been educated to detect any difference between the qualities of the touch sensations derived from them. A two-year-old child cannot even indicate correctly the foot which has been touched.

The power to localise tactile sensations can be tested by means of a pair of compasses. When the points of the compasses are placed on the tip of the tongue only $\frac{1}{20}$th inch apart, they will be felt as two points. In order to be felt as two points, the compasses must be opened

about	$\frac{1}{12}$	inch	on the	tip of the forefinger,
,,	$\frac{1}{6}$	,,	,,	under lip,
,,	$\frac{1}{4}$	,,	,,	tip of the nose,
,,	$\frac{1}{2}$	,,	,,	palm of the hand,
,,	1	,,	,,	back ,, ,,
,,	2 to 3	,,	,,	back of the neck.

Thus while the error of localisation is very great in the back, it is very small in the tongue and fingers.

The more intense the stimulation, the more accurate is the localisation. From the compass experiments we learn that skin areas $\frac{1}{20}$th inch apart on the tip of the tongue have different local signs. The areas or *sensation circles*, as they are called, are $\frac{1}{12}$th inch apart on the finger-tips, and 2 to 3 inches apart on the back. We naturally use the fingers, and not the back, to feel for an object in a dark room. By recognising the area of skin that any object happens to touch, we can roughly judge its size.

Shut your eyes and ask another to place a piece of wood on the palm of the hand. Estimate its size and then open the eyes. You will at once recognise that the eye measures the size far more accurately than the skin. Repeat the experi-

ment, only this time estimate the size of the object by *moving* your fingers over it.

To estimate accurately the size and form of an object, we either look at it or actively touch it.

The normal man constantly corrects his tactile sensations by means of his visual sensations. The blind man depends entirely upon touch in estimating the size and form of objects. If a man, blind from birth, suddenly recover his sight by means of an operation, he is at first bewildered, for he has never learnt to associate eye and touch sensations together. Such a man has to train himself to form correct visual judgments by feeling each object that he looks at.

On striking 'the funny-bone' a strange tingling sensation is felt in the fingers. This sensation arises from the stimulation of the ulnar nerve, which lies behind the elbow and is jarred by the blow. Owing to habit we associate any impulse that comes up the ulnar nerve with the part of the skin which is supplied by the nerve in question. Similarly, a man with an amputated leg continues for some time to feel his lost foot and toes, for any sensation arising from the stimulation of the nerves in the stump is referred by habit to these parts.

Beside learning its position and form, we recognise, on touching an object, whether it be smooth or rough, blunt or sharp, sticky, velvety, &c. Such qualities seem to depend on the extent, intensity, and duration of the stimulation. The prick of a pin produces an intense sensation limited to a very small area. A sticky substance clings to the finger, while a soft substance gives to the pressure of the same. A rough surface touches the skin only at certain places, while a smooth surface touches it equally at all points. At the same time substances like metals, which conduct heat from the skin, feel cold, while bad conductors such as cloth, feel warm. One can be easily deceived regarding smoothness.

Get a piece of wide-meshed wire gauze and put the hands on

each side of it opposite one another. Move them along the surface and you obtain a sensation of oily smoothness.

In estimating the size of objects by actively touching them, we employ the muscular sense in addition to the sense of touch.

The muscular sense. Close your eyes and direct your attention to the position of the right hand. The nerves in the joints inform us how far the articular surfaces are in contact. The nerves of the tendons tell us which muscles are flexed or which extended. By means of the sensory nerves in the muscles we estimate the effort required to support the weight of the hand. At the same time, the tactile nerves in the skin inform us whether or no the palm of the hand is touching the fingers. Open and close the hand—the sensations change with each position, and thereby we learn the extent of the movement. By means of the muscular sense we are kept informed as to the position of our body and limbs.

The muscular sense can be used to roughly compare the weight of objects, for we become conscious of the amount of effort put forth by the muscles in lifting weights.

You will find that it is easy to estimate a slight difference between two light weights, while if the same difference be made between two heavy weights, it is not possible to detect which is the heavier. For example, you can just detect, on weighing them in your hand, a difference between a weight of 20 ounces and another of 21 ounces. Now lift in turn weights of 40 and 41 ounces. You cannot tell which of these is the heavier.

The greater the weight is, the larger must the additional weight be made in order that you may detect a difference. A similar law holds true for the other sensations. Suppose a paper screen be illuminated with 100 candles, the addition of one candle will perceptibly increase the light. Let the screen be now illuminated with 1000 candles.

In this case, not one, but ten candles must be added before any increase in the intensity of the light can be perceived. From these experiments we learn that the intensity of sensation does not increase in the same proportion as the strength of the stimulus. As the stimulus grows in intensity, the increase in sensation becomes steadily less. This is a matter of no little importance, for we are thus enabled to detect the slighter differences in weak sensations, while we are not overwhelmed by the more powerful ones.

Sensations of hot and cold. The skin is continually gaining and losing heat, and so its temperature varies. The gain depends on the amount of warm blood flowing through the skin ; the loss is due to the exposure to the air. On a hot day the air is warm, the cutaneous blood-vessels are dilated, the skin is flushed with blood, thus the gain is greater than the loss. The temperature of the skin may then be 97° F., or almost as hot as the blood. Any object cooler than 97° F., when brought in contact with the skin, will in such case feel cold, while any object at a temperature above 97° F. will feel hot.

On a cold wintry day the cutaneous blood-vessels are constricted, and the skin temperature is less than that of the blood, say 90° F. We should then feel objects hotter than 90° F. to be warm, while objects below that temperature will seem cold. Obviously, then, our sensations of hot and cold depend on the temperature of the skin. You can prove this to be so by carrying out the following experiment :—

Place one hand in cold and the other in hot water, then plunge both in lukewarm water. To the cold hand the lukewarm water will appear hot, while to the warm hand it will seem cold.

Suppose you feel a child's toes—if your hands are warm and flushed the child may seem to be cold, while if your

hands are cool you may imagine the child to be hot. In either case your conclusion may be wrong. To gain a correct idea of the temperature of another a thermometer, and not the hand, must be used.

It is a common practice of nurses to test the heat of a child's bath by plunging in their elbow. The skin is there protected by clothes, and will, on pulling up the sleeve, be almost at blood-heat. By this means the nurse can more accurately determine whether the bath be hotter or colder than the body.

The sensitiveness of the skin to changes of temperature varies in different parts of the body. A washerwoman holds her iron near her cheek to tell whether it be too hot. The palms of the hands and the bends of the joints are also sensitive parts. In hot weather a grateful sensation of coolness can be attained by pouring cold water on to the wrist or elbow joints. There is reason to think that the nerve-endings in the skin which are sensitive to temperature differ from those which are sensitive to touch.

Take a piece of metal with a blunt point, and after placing it in hot water touch different points on the front surface of the arm. At some points you will distinctly feel heat, and at other points only a touch. Mark the heat points with spots of ink. Repeat the experiment after cooling the metal in iced water. Here again you will feel at some points cold, at others a touch. Mark out the cold points.

Take bristles from a soft broom and stick pieces of them, about an inch long, on matches (at right angles to the end). Find a bristle which, when pressed on the arm till it bends, can just be felt. Mark out touch spots with this. Spots more or less sensitive to pain can be found by using a needle.

CHAPTER XXXIII

LIGHT.

Light. The organs of touch are excited by the impact of masses of matter, while those of taste and smell are stimulated by the impact of molecules of matter, either in solution or in a state of vapour. The organ of hearing is excited by the impact of waves of sound, and these are produced by the rhythmic vibrations of elastic substances, for such, after distortion or jarring, swing to and fro before coming to rest. The waves of sound are conducted from the sounding body to the ear by means of the air. Sound-waves will not pass through a vacuum, thus we cannot hear a bell set ringing in a glass vessel pumped free of air.

Light behaves differently from sound, for it can pass through a vacuum, and the eye perceives the light of a candle placed near at hand and that which comes through space from the infinite distance of the stars. Light can penetrate through layers of glass, water, horn, and many other kinds of matter. Owing to these and many other facts, it has been conceived by man that all space and all matter is pervaded by intangible, unweighable particles called *ether*. The particles of ether, it is imagined, fill the space between the earth and the stars, and everywhere penetrate between the molecules of matter.

The particles of ether are, we believe, set trembling by the molecular vibration of matter. Light and heat are diffused through space in all directions by the vibrations of these particles.

Suppose you have set a smith to hammer a piece of cold iron in a dark room. With each blow you hear a sound and may, at the same time, feel the floor shaking. After he has hammered for some little time, touch the piece of iron; it will be hot to your hand. Let him then hammer with greater vigour; the iron will become visible, of a glowing, red colour, and intensely hot. In this experiment the senses of hearing, touch, temperature, and sight are severally excited, and the cause of the excitation in each case is the energy imparted to the iron by the smith's muscles. By the stroke of the hammer upon the anvil the floor is shaken. The floor jolts against the feet and excites the touch-organs there. The hammer, the iron, the anvil are elastic substances. These are thrown into vibration by each blow and produce sound-waves in the air. The latter travel to the ear, and there excite sensations of sound.

The energy of the smith is mainly imparted to the molecules of the iron, and the intense vibration (heat) set up in these is communicated to the ether. The eye is sensitive to the more rapid, the skin to the slower vibrations of the ether. The greater the energy imparted by the smith to the molecules of iron, the higher becomes the molecular vibration or temperature of the iron. To begin with, invisible heat-waves alone stream forth. These, if the hand be held near the iron, warm the skin, and produce a sensation of heat. As the temperature is raised higher and higher by the blows of the smith, more rapid waves are produced. These excite the sense-cells in the eye, and then we become conscious of light.

Light is produced during many chemical combinations

owing to the high temperature or intense molecular vibration that then results. A candle is luminous because of the intense molecular vibration produced by the combustion of the tallow. Similarly, a solid lump of phosphorus burns when dropped into a jar of oxygen. If the process of chemical combination be slow, the heat may be lost as rapidly as it is formed; then the temperature does not rise, and light is not produced. Such is the case with the process of combustion that takes place in the body of man; heat, and not light, radiates from him. In some animals there are developed special organs which produce a peculiar glow known as phosphorescent light. The glow-organ in the tail of a glow-worm consists of protoplasmic cells. The cells cease to be luminous so soon as the supply of oxygen is withdrawn. Certain fish that live in the dark depths of the sea carry a searchlight by which they illuminate their prey. The phosphorescence of the sea is caused by the growth of light-producing bacteria.

The Röntgen light is produced by the passage of intense electric currents across a glass vacuum-tube. This kind of light has the power to penetrate through many substances which are opaque to ordinary light, for example the flesh of man. By its means, a shadow of the bones and denser structures of the body can be thrown upon a screen. By the help of the Röntgen light not only the heart and diaphragm can be seen moving in a living man, but fractures and dislocations of bones can be viewed, while shot, bullets, needles, and other foreign bodies can be found.

The light of the stars, the light and warmth of the sun, it is supposed, result from the intense molecular vibration of the chemical substances of which these glowing orbs are composed. Light travels with enormous velocity. Suppose a man stand on the seashore at night-time, and with a powerful lamp flash light at a mirror placed a quarter of a mile

away. The light will be reflected and come back to him so quickly that no interval of time can be noticed. Suppose he set in front of the lamp a bicycle wheel, and the wheel be covered with a sheet of brown paper, except at one place where a small gap is cut. Behind the gap, the lamp and the man's eye are placed. When the wheel is set spinning, the lamp, at each revolution, flashes through the gap, hits the mirror, and returns. If the wheel be set spinning fast enough, the light may, on its return, be blocked, for the brown paper will have revolved into the space just previously occupied by the gap. When this is so, the reflected light will not reach the eye of the man. The rate with which the wheel must be spun to produce this effect can be measured. By such means it has been determined that light travels 186,000 miles a second. Yet so distant are some of the stars that astronomers calculate their light spends more than a thousand years in travelling from them to the earth.

Reflection of light. Water and glass are transparent and allow part of the light to pass through, while part is reflected. You know how a window reflecting the sunlight may appear as a gleaming spot in the landscape. Rays of light are reflected in much the same way as the waves of the sea. These are thrown back when they strike against a cliff. From a piece of polished metal almost all the light is reflected, while from a layer of lampblack but little light is reflected, for it is almost all absorbed.

Rays of light move onwards in straight lines so long as they continue to travel through one and the same substance. When they meet a second substance they may penetrate through this, or they may be reflected, or they may be absorbed. If the substance be opaque the rays do not penetrate it for any great distance; they

are partly reflected and partly absorbed. On the other hand, if the substance be transparent the rays are partly reflected and partly absorbed, but the larger part continue to travel onwards.

When the light from an object strikes a flat mirror it is reflected so that the image appears to lie at the same distance behind the mirror, and in the same plane as the object in front.

By a concave mirror rays of light are *converged* to a focus.

Hold a candle in front of the concavity of the polished lid of a saucepan. The reflected rays are converged to a focus, and a small, real, but inverted image is formed in front of the lid.

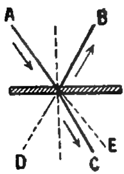


FIG. 151. The ray of light A, E striking a sheet of glass, is partly reflected to B, and partly passes through the glass and is refracted to C. The reflected ray appears to come from D.

Concave mirrors are used to converge the light of a lamp on any spot, and thus brilliantly illuminate it. By means of a small concave mirror pierced with a round hole, a doctor can illuminate an eye of a patient, and, at the same time, by peeping through the round hole he can see into the eye. He uses a concave mirror in the same way to illuminate the ear and the throat.

Look at the reflection of a candle in the convex surface of your watch-glass. You see the image of the candle to be small and erect. It appears to lie behind the glass.

When rays of light strike a convex mirror they are reflected, and, at the same time, scattered or made to diverge. The reflected rays in this case appear to come from an erect image situated behind the mirror. The image does not really exist, but from the direction of the rays we imagine that it must be there.

Refraction of light. On passing from one substance into another, say from air into water, the light-rays are bent or refracted out of their previous course. They follow a new straight line through the second medium.

Put a penny in a pudding-basin and place your eye so that the edge of the basin just conceals the penny. Now fill up the basin with water, and the penny will become visible. The light reflected from the penny is bent as it passes out from the water into the air and so reaches the eye. Similarly, a stick appears bent when one-half of it is immersed in water.

Paste a broad line of some sticky substance, such as treacle, on a smooth table and send a pencil rolling along the table so that it will enter the sticky line obliquely. The pencil will swivel round and change the direction of its course. So is it with light.

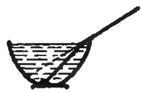


FIG. 152. Refraction of light. A penny in a basin of water.

On entering a denser medium the rays are bent towards the perpendicular, while on leaving a denser for a less dense medium they are bent from the perpendicular.

Lenses Examine the spectacle-glasses of long and short-sighted people; you will find that those of the former are thicker in the centre than at the edges, while those of the latter are thicker at the edges than at the centre. Look through a thin-edged or *convex* lens at a printed page; the lens acts as a magnifier. At the same time, the enlarged image of the print appears further away than the rest of the page. The eye has to be adjusted as if you were looking at a more remote object. On holding such a convex lens between the sun and a sheet of paper, it will produce a clear, round, and small image of the sun, and act as a burning-glass. The more bulging the lens, the nearer it must be held to the paper to produce the sun image. The distance any lens must be held from the paper to produce an image of the sun is called the *focal distance* of the lens in question. Convex lenses converge rays of light, that is, they bend the rays towards the axis, where the lens is thickest.

Thick-edged or concave lenses, on the other hand, cause light to *diverge* and bend away from the axis towards the thicker edges.

If you look at a landscape through a concave lens the image appears both diminished and nearer. The eye has to be adjusted as if looking at a near object.

Take a thin-edged or convex spectacle-glass and hold it at arm's length in front of a candle-flame. A small inverted image of the candle will be seen, hanging, as it were, in air, somewhere between your eye and the lens. Move a piece of thin transparent paper forward towards the lens; at a certain place the image of the flame will appear sharply defined on the paper. On first moving farther away from, and then nearer to the

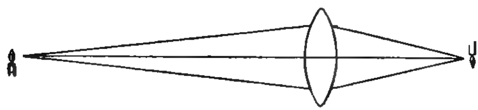


FIG. 153. A convex lens brings the rays of light from a candle to a focus and produces an inverted image of the flame.

candle, you will find that the image appears nearer to the lens the farther you go from the flame. The image formed by the sun will be nearest of all to the lens.

Now take a thick-edged or concave lens and try to find where it forms an image of the candle; you will not succeed. It only appears to us as if there were an image at a certain distance on the other side, that is, behind the lens.

A convex glass converges the rays of light coming from the flame to a point in front of the lens where the real image is formed. The concave glass diverges the rays and makes them appear as if they came from a point behind the lens; the image of the flame seen there is an imaginary one and not real. The *compound microscope* in its simplest form is composed of two convex lenses placed at either end of a tube, the one is the object-glass or objective, the other the eye-piece or power. The object-

glass is placed near the object to be viewed, and this is illuminated by light reflected to it from a mirror. An inverted and enlarged image of the object is produced on the other side of the object-glass, and this image appears still more highly magnified when viewed through the eye-piece. The image is focussed by sliding the tube of the microscope nearer to or farther from the object.

CHAPTER XXXIV

THE STRUCTURE OF THE EYE.

The eyelids. The eyeball is a globular organ lying in the cavity of the orbit. The cavity is padded with fat, which affords to the eye a soft elastic cushion. When this fat wastes away the eyes become sunken in appearance. The walls of the orbit protect the eye, except in front, and there it is guarded by the eyelids. The eyelids are folds of skin. The inner moist surface of the lid is covered with a thin layer of epithelium. This is continuous with the thicker stratified epithelium on the outer side of the lid. The thin epithelium on the inner side of the lid is called the *conjunctiva.* The conjunctiva leaving the lid passes off on to the white of the eye and runs over this. The lids thus form a circular closed pouch, and a probe inserted under an eyelid cannot be passed to the back of the eye. Along the edge of each lid, just behind the eyelashes, there open the ducts of some small glands. A stye is produced by the blocking of one of these ducts. The eyelashes protect the eye from too much light and give warning of the approach of twigs, insects, &c. When an eyelash is touched, the sensory nerve-fibres twining round the root of the hair in the eyelid are stimulated, and reflexly the eyelid blinks. The conjunctiva is supplied with nerves and blood-vessels; the latter

become engorged and the eye bloodshot when the conjunctiva is inflamed. Muscle-fibres circle round both eyelids, and by their means the lids are closed. The upper lid can be raised by another muscle, which enters it from above.

The eyelids blink every few seconds. Excitation of either the optic nerve by light, or of a branch of the fifth cranial nerve by touch (the last supplies the conjunctiva), reflexly produces a blink. The motor nerve supplying the muscles of the lid is the seventh cranial nerve. On the upper and outer side of the orbit is placed the *lachrymal gland.* This is like a salivary gland in structure, and secretes a thin watery fluid, the tears. This fluid constantly washes over the conjunctiva, and cleans away dust from the eye. A particle of dirt in the eye makes it water. There is a small opening on each eyelid close to the inner corner of the eye. These openings lead to a duct, by which tears pass down to the nose. If the duct become closed the fluid overflows and the eye continually waters. Very young infants for the first two or three months of life do not shed tears when crying. Weeping is always associated with contraction of the muscles of the eyelids. These muscles contract on any strong expiratory effort, as during violent coughing or laughing, and tears may then flow just as in sobbing. The contraction of the eyelids causes pressure on the eyes and prevents them being over-engorged with venous blood during the expiratory efforts. The flow of tears can be reflexly excited by almost any violent sensory stimulation, for example, irritation of the nose by pepper.

Dissection of the ox eye. Obtain from the butcher several fresh bullock or sheep's eyes.

In front of the eye is a clear transparent area which is more strongly curved than the rest of the globe of the eye. This is the *cornea.* Outside the cornea there lies the white of the

eye. This is formed by the *sclerotic*, which is here covered with the conjunctiva. Towards the back of the eye the sclerotic is covered with fat. On removing the fat at the back of the eye you will find a short piece of a thick round nerve piercing the sclerotic. This is the *optic nerve*. The optic nerve does not enter the eye exactly opposite the centre of the cornea, but a little to the inner side, that is, nearer the nose. The pad of fat surrounding the back of the eye is covered by a sheet of muscle. The sheet of muscle can be separated into six distinct muscles, each of which has been cut short in removing the eye from the orbit.

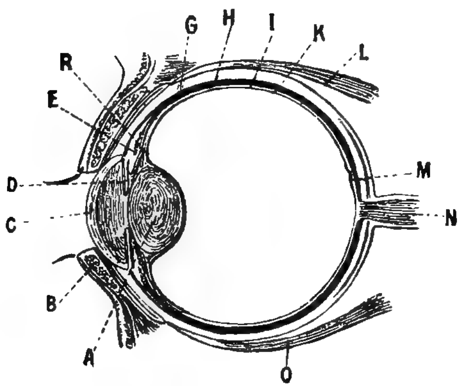


FIG. 154. Section through eye. A. Lens. B. Eyelid. C. Cornea. D. Iris. E. Ciliary muscle. G. Sclerotic. H. Choroid. I. Hyaloid membrane enclosing vitreous humour. K, M. Retina. L. Superior rectus. N. Optic nerve. O. Inferior rectus muscle. R. Suspensory ligament of lens.

The eye muscles. Each muscle is attached by a short tendon to the sclerotic just behind the cornea. The other ends of the muscles are attached, when the eye is in its place, to the bony wall of the orbit. By means of these muscles the eye can be turned in any direction. Four of the muscles pass straight forwards from the back of the orbit to be inserted in front of the eyeball. These are called rectus or straight. The *external rectus* moves the eye outwards, the *internal rectus* inwards, the *superior* and *inferior rectus* respectively upwards and downwards. The remaining two muscles pass obliquely to their attachment on the eye. These are called the *superior* and *inferior oblique*. The superior oblique works with the inferior rectus, the former steadying the eye while the latter pulls it down. The inferior oblique aids the superior rectus in

the same way. When we look from a far to a near object both eyes turn inwards or converge upon the object.

The image formed by the eye. In the back of a *fresh* ox eye cut out a small window with a pair of sharp-pointed scissors. Then hold the eye in front of a candle with the cornea pointing towards the flame; you will see shining in the window a little inverted image of the flame. On placing a cigarette paper over the window, the image will appear on that, and should the eye be quite fresh and not flabby the image will be focussed quite sharply on the paper. This experiment proves that the eye is so constructed as to throw a little inverted image of any external object on to the back of the eyeball.

The coats of the eyeball. Now take the ox eye, and with a sharp razor cut it cleanly, from front to back, into two halves. The eyeball is enclosed by three coats, the *sclerotic*, the *choroid*, and the *retina*. It is divided by the convex transparent *lens* into a shallow *anterior*, and a large *posterior chamber*. The latter is filled with a gelatinous substance, the *vitreous humour*. The lens and the vitreous humour easily come away together. The vitreous humour is enclosed in a transparent membrane, the *hyaloid membrane*. The internal coat or retina is very thin and of a greyish colour; it peels off quite easily except at one spot, where it is found to be continuous with the optic nerve. The latter, on its entrance into the eyeball, expands into the retina. The retina is the sensitive coat of the eye. On peeling off the retina, a black coat, the choroid, is exposed; outside this is the strong fibrous coat or sclerotic. The sclerotic protects the delicate parts of the eye, and holds all together, framing the eye into the shape of an elastic ball. It is composed of an interlacing network of white fibrous tissue. The muscles which move the eye are attached to the sclerotic. The choroid forms the dark lining of the eye. The light which enters the eye through the pupil, after passing through the retina, is absorbed by the choroid. Reflection is thus prevented, while, at the same time, the choroid stops the entry of light through the sclerotic. The inside of a photographic camera is, for the same purpose, coated with black. The choroid forms a vascular sheet for the blood-vessels which

pierce the sclerotic; these spread out over it and form a wonderfully close network of capillaries. The capillaries lie just behind the retina, and nourish the latter. The black colour of the choroid is due to branching cells which form a network in the choroid among the capillaries, and contain particles of dark pigment. In many animals the choroid is iridescent with colours, hence the green sheen of a cat's eye. On the other hand, the light reflected from the back of a man's eye appears red. This is due to the blood in the capillaries of the retina, for the choroid is not iridescent.

In front of the lens lies a pigmented sheet or diaphragm, the *iris*. The iris is pierced by a round hole, the *pupil*. Between the iris and the cornea there lies the shallow anterior chamber of the eye. This is filled with a transparent liquid, the *aqueous humour*. All these parts must be examined with the greatest care.

The iris and lens. Take another ox eye, and, with sharp-pointed scissors, cut round the edge of the cornea. Remove the cornea and examine the iris and the pupil. The pupil of the ox eye is a slit; in man, it is a round hole. The iris is pigmented, and, if there be much pigment present, the colour of the eye is dark brown, while, if the pigment be little in amount, the eye is blue or grey in colour. The iris contains muscular fibres, by means of which the pupil can be made to dilate or constrict. Lift up the edge of the iris, and you will see the lens lying behind it. The iris is a continuation of the choroid coat. The choroid forms a fringe of black pigmented folds lying all round and just behind the thin edge of the lens. These folds are called the *ciliary processes*. The hyaloid membrane at this point gives off a thin sheet of transparent tissue which is fastened to the edge of the lens and holds it in place. This sheet is called the *suspensory ligament*. At the point where the choroid passes in front of the lens it forsakes the sclerotic and spreads out to form the iris.

Rays of light cannot pass through the thin edge of the lens owing to the pigment in the iris. The rays are thus confined to the thicker central portion of the lens. In the same way a photographer employs a diaphragm placed in front of the lens of his

camera. By such means he confines the light to the central part. The reason for such a contrivance is that the thin edge of a convex lens does not refract the light to the same degree as the thicker central part, and therefore, when light passes through all parts of the lens, the image is not sharply brought to a focus, but is blurred. To prevent this blurring, a diaphragm or iris is interposed both in the camera and the eye.

Slip the point of the scissors underneath the iris, and notice that the latter is not attached to the lens, but hangs in front of it. Then cut through the iris in two places, and turn the flap outwards. You will now see that the iris joins the choroid just at the point where the sclerotic passes into the cornea. The black fringe of the ciliary processes will also be seen behind the outer edge of the lens, and the transparent suspensory ligament attached to the edge of the latter. Tear through the suspensory ligament and press the eyeball; on doing so, the whole of the lens will slip out, leaving the impression of its form on the front surface of the vitreous humour. The lens is a beautiful transparent body, convex both in front and behind. Stick a pin into the edge of the lens and hold it by this closely over some print and see that it magnifies the letters, then hold it at arm's length between your eye and a candle-flame. In front of the lens there will appear a little real but inverted image of the flame. The farther you go from the candle the nearer to the lens will the image be formed; you can prove that this is so by focussing the image upon a piece of transparent paper. According to the distance from the candle you will have to move the paper near to, or farther from, the lens.

Accommodation. Since the retina or sensitive screen upon which the image is formed is fixed in position, it is clear there must be some means by which the image, either from far or near objects, can be focussed sharply on the retina. The photographer focusses the image sharply on the ground-glass screen at the back of his camera, either by moving the screen backwards or forwards, or by screwing the lens nearer or farther from the

screen. In the eye of a fish, the lens can be moved backwards and forwards by a muscle situated within the eye, but in the eye of a man and the higher animals, both the lens and the retina are fixed in position. Some other focussing mechanism must therefore be sought for. This is to be found in a little band of muscle which, arising from the fibrous tissue at the junction of the cornea with the sclerotic, runs to the choroid and ends in this coat near where the suspensory ligament is attached to the lens. The muscle encircles the edge of the lens, and is called the *ciliary muscle.*

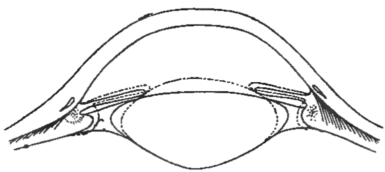


FIG. 155. Section through anterior part of eye. The diagram shows how the anterior surface of the lens becomes more convex during accommodation for near vision.

By very carefully cutting through the sclerotic at the edge of the cornea, and turning a flap of this coat downwards, the muscle may be seen as a narrow greyish band lying on the black choroid.

On a strip of card stand a convex lens, and fix it with a little sealing-wax or putty in the upright position. Behind the lens, with a couple of pins fix a screen of tissue paper. Place a candle at such a distance in front of the lens that its image is focussed sharply on the tissue paper. Now replace the lens by a stronger or more convex one, and moving the candle, find the position in which it must be placed for the image to be focussed on the tissue paper. The candle will have to be brought nearer to the lens.

This experiment proves that the image of either a far or a near object can be focussed on a stationary screen if the lens be made in the one case less, in the other more convex. Now the action of the ciliary muscle of the eye is such that it makes the lens more convex, by this means

the images of near objects are focussed on the retina. The eye is so constructed that images of far-off objects are brought to a sharp focus on the retina, so long as the ciliary muscle is not in action. So soon as we look at a near object the ciliary muscle contracts, and the lens becomes more convex, at the same time the eyes turn inwards and converge on the object, while the pupils contract.

Observe the movement of the eyes and the pupils when a person looks from a far to a near object.

Experimental proof of accommodation. That the lens does become more convex can be proved in the following way:—

Stick up with putty three watch-glasses on a strip of card. Place them one behind the other and close together. Let the two front have their convex surface, and the hind one its concavity turned towards a candle-flame. You will see three images of the candle reflected. The first is erect, and apparently lies behind the first convex lens. The second is erect, and apparently lies behind the second convex lens. The third is a real inverted image, and lies in front of the third or concave lens. On replacing the second glass by a still more convex watch-glass, the image reflected from it will be seen to be smaller in size.

Now throw the light from a candle sideways into a person's eye. On looking into the eye you may be able to detect three tiny reflected images. The first is very bright, erect, and apparently lies within the eye. It is reflected from the convex cornea. The second is erect, but much less bright; it also apparently lies within the eye. This one is reflected from the convex front surface of the lens. The third is faint, inverted, and real. It is reflected from the hind surface of the lens, or, more accurately, from the front concave surface of the vitreous humour. If the person look from a far-off to a near object, the *second* image will alter in position and become smaller in size. This proves that the anterior surface of the lens becomes more convex.

Owing to the power of altering the shape of the lens (*accommodation*), we are able to see clearly the stars and the moon, ships on the horizon, or objects held as near as six inches to the eye. The eye cannot, however, see far and near objects clearly at one and the same time.

Hold up two fingers, one near and one far off from the eye. Focus the near one, the far one becomes blurred and indistinct, while on focussing the far one it is the near one that becomes blurred. If, while looking at a printed page, you open your eyes wide and keep them so, the page will gradually blur, for the ciliary muscle relaxes. The relaxation of the latter is associated by habit with the opening of the eyes, for the eyes open whenever you look up from the page of a book across the room.

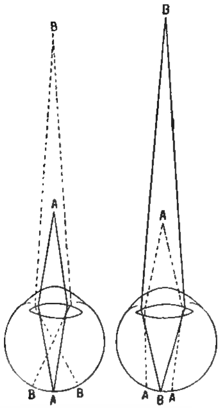


FIG. 156. Diagram to show how the images of the near and far pins fall on the retina in the experiment on accommodation. A. near pin. B. far pin.

With a needle prick two holes in a card about $\frac{1}{16}$th inch apart, that is, closer together than the diameter of the pupil, so that you can see through both holes at once with one eye. Tack the card at one end of a strip of wood (a yard measure will do). At the other end of the board, stick up a pin. Finally, stick up another pin about eight inches from the card. Now close one eye, and, with the other, look through the holes in the card at the near pin, turning the board towards a window. The far pin will appear double.

The rays of light coming from the near pin through either hole in the card meet together on the retina, and are thus focussed into a single image. On the other hand, the light coming from the far pin through the two holes is not focussed *on*, but *in front* of the retina.

Diverging off from this focus the rays separate, fall on the retina at two different spots, and thus we are conscious of

a double image. On closing the *right*-hand hole with another card, the *right*-hand image of the far pin will disappear. This image, as is made clear by the diagram, fell on the left side of the retina, and any excitation of the left half of the retina is judged by the brain to come from the right half of the field of vision. Next focus the far pin, and observe that a double image of the near pin at once becomes apparent. The rays of light from the near pin are not focussed on, but behind the retina, for the lens is not sufficiently convex. Close the right-hand hole, and the image of the near pin which lies to the left will disappear. This is because the rays of light which enter by the right-hand hole fall on the right side of the retina, and the brain judges all excitations of the right half of the retina to come from objects placed on the left hand of the field of vision.

The mode of action of the ciliary muscle. The fibres of the ciliary muscle are arranged in two sets. The one set radiates from the junction of the cornea and sclerotic to the choroid. The other set circles round the edge of the lens. In the fibrous tissue forming the junction of the cornea and sclerotic there are some loose spaces connected with veins. The radiating muscle-fibres by their contraction pull open these spaces, and, at the same time, pull up the choroid, and so slacken the suspensory ligament. The circular fibres on contracting slacken the suspensory ligament, and possibly squeeze the margin of the lens. The anterior surface of the lens becomes more convex so soon as the suspensory ligament is relaxed. The change is attributed to the natural elasticity of the lens. The aqueous humour at the same time escapes into the venous spaces, and so makes room for the expansion of the lens. Possibly the ciliary muscle acts in the following way :—

1. It pulls open the venous spaces and allows the escape of the aqueous humour.

2. It pulls up the choroid and increases the pressure of the vitreous humour against the back of the lens.

3. It squeezes the edge of the lens.

As a result of these three changes the front surface of the lens would become more convex.

It seems probable that the explanation given first is the true one. Stick a needle vertically in a piece of cork and look at it from a distance of a few inches. Then shake the head violently from side to side. Now look at the needle again. Very likely this will appear to move from side to side for a moment. The apparent movement of the needle shows that the lens is no longer fixed firmly but wobbles from side to side as it would do if the suspensory ligament became slack.

Short sight and long sight. Many people are born with defective eyes. The lens is not always developed of the right convexity, or, to put it in another way, the retina is developed either too near or too far from the lens. In old age the eye loses its elasticity, and the eye can no longer be accommodated for near vision. In all such cases glasses can be worn to correct the detect in the eye. A *short-sighted* person has an eyeball that is too *long*. Rays of light from far objects are focussed in front of the retina, and only near objects are focussed on the retina and can be seen distinctly. This condition can be remedied by wearing concave glasses, which throw the image of far objects further back.

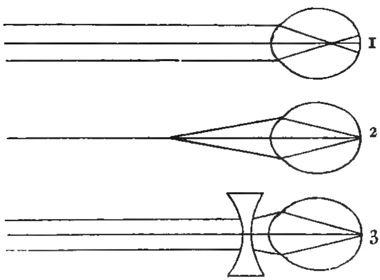


FIG. 157. Short sight, or myopia; eye too long. 1. Rays from far object brought to a focus in front of retina. 2. Rays from near object brought to focus on retina. 3. Rays from far object brought on to retina by use of concave lens.

On the other hand, in a *long-sighted* person the eyeball

is too *short*, and the retina lies too near the lens. Images of far objects are then brought to a focus on the retina, but in order to see near objects the ciliary muscle must strain to the utmost to make the lens sufficiently convex. The eye of a long-sighted person is thus always in a condition of strain when the person reads, sews, &c. This strain generally leads to headache and fatigue. Young people who suffer from headaches should make certain whether or not they are victims of long sight, for the right kind of glasses may afford them an immediate cure. Long-sighted people must wear convex glasses in order to converge the rays from near objects on to the retina, and these glasses must be worn continually during the execution of all kinds of close work. Short-sighted folk, on the other hand, need only wear their glasses to see distant objects; for close work, a slight amount of short sight is an advantage. In old age, the eyes become long-sighted, owing to the decreased elasticity of the lens. Thus old people take to wearing convex glasses for reading and close work. People who are somewhat short-sighted in youth become of normal vision in old age and so escape wearing glasses.

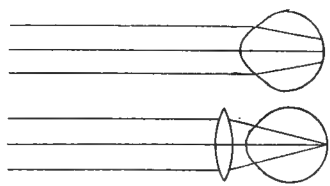


FIG. 158. Long sight, or hypermetropia; eye too short. Rays focussed behind retina, brought to a focus on retina by use of convex lens.

Sometimes the cornea (more rarely the lens) is not curved equally in all conditions. It may, for example, appear more curved when viewed from the side than when seen from below. This produces a condition called *astigmatism*. The two arms of a cross cannot be sharply focussed at the same time by an astigmatic eye, for the rays from one limb of the cross are converged by the cornea more than the rays from the other limb, and so the rays are

not brought to the same focus. This is owing to the unequal curvature of the cornea. The astigmatic condition can be corrected by a cylindrical glass. This is shaped like a piece cut out from the wall of a glass tumbler, for such a piece is curved in one direction only, and can be so placed in the spectacle-frame as to correct the under curvature of the cornea.

Action of the iris. Set up a convex lens with the help of sealing-wax or putty. In front of it place a candle, and behind it a screen of tissue paper. Move the screen until the sharpest focus of the candle-flame is obtained, and then fix it in position. Now put in front of the lens a piece of black paper, with a round hole cut in it about the size of a threepenny bit. A sharper, but less bright, image of the flame will now be obtained. The paper diaphragm or 'stop' cuts off the rays which come through the thin edge of the lens. These rays are not brought to exactly the same focus as the rays which pass through the central part of the lens, and thus the image, if no diaphragm be used, is slightly blurred. A photographer uses a 'stop' in his camera to render the image sharp.

If the candle be placed a long way off, a better image is obtained by widening or even removing the diaphragm, for the light is, in this case, so faint that it is best to allow the lens to gather up all the rays it possibly can.

In the eye the iris plays the part of a photographer's 'stop.' Watch another person's pupil. It becomes small (1) when the eye is directed to a near object, (2) when the light is strong. On the other hand, the pupil dilates (1) when the eye is directed to a far object, (2) when the light is feeble. Observe the slit-like pupil of a cat in the daytime, and the wide open pupil of the same animal in the twilight.

The pupil dilates with fear and constricts during sleep. If you lift up the eyelid of a sleeping child you will see the pupil to be very small.

The iris contains a double set of muscle-fibres. The

one set forming the *sphincter* of the iris circle round the margin of the pupil. When these contract the pupil becomes smaller. The other set radiate from the margin to the outer limit of the iris. These fibres pull open the pupil and make it larger; they constitute the *dilator* muscle of the iris. The sphincter muscle is supplied by branches of the third cranial nerve; it contracts reflexly when the optic nerve is stimulated by strong light. The dilator muscle receives fibres from the sympathetic system. These fibres issue from the spinal cord in the upper part of the thorax. The drug belladonna or atropine, when applied to the eye, for a time paralyses the sphincter muscle and produces a widened pupil. Doctors apply this drug when they wish to examine the back of the eye. Any one who experiences such temporary paralysis knows how important the iris is, for he is bothered by strong light, and cannot read or see near objects plainly.

Structure of the cornea. The cornea is transparent, the sclerotic opaque. The sclerotic is formed of a felt-work or tangle of connective-tissue fibres, through which the light cannot penetrate. The cornea is composed of flat sheets of connective tissue laid evenly one over the other, and thus is transparent as glass.

The cornea contains no blood-vessels, but is nourished by lymph. The absence of blood-vessels helps to make the cornea transparent. On its outer side the cornea is covered with stratified epithelium; through the substance of the cornea there runs a network of nerve-fibrils, which render it very sensitive. A thin film of cells separates the substance of the cornea from the aqueous humour which occupies the anterior chamber of the eye.

The blind spot. The optic nerve on entering the eye spreads out into a thin film of nerve-fibres, forming the

innermost layer of the retina. Blood-vessels enter with the nerve and likewise branch over the retina. You can see these in a fresh ox eye after cutting a window in the side of the eye. The entrance of the optic nerve is then apparent as a small circular white patch. If a small beam of light be thrown into a man's eye, so as to fall on this white patch, no sensation of light results. The optic nerve itself is not sensitive to light. The patch formed by the entrance of the optic nerve is called the blind spot. We are not naturally aware of the existence of a blind spot, but a simple experiment proves to us that such exists.

Mark a dot and a cross on a sheet of paper about 3 inches apart (the cross on the right side), and hold it about 10 or 12 inches away. Shut the left eye, and with the *right* look at the *cross*. Move the page nearer while steadfastly continuing to look at the cross. At a certain distance the spot will disappear. Repeat the experiment, this time shutting the right eye and looking at the *spot* with the *left* eye. At a certain distance the cross will disappear. In each case, both spot and cross will be seen on moving the book still closer to the eye.

Take a clean sheet of paper, a book, and a long pencil. Stand up the book on the paper, and rest your forehead on the top of it. Mark a cross on the paper just to the right of the book. Look at this with the right eye and shut the left. Then move the pencil point along the paper from right to left. Mark both the place where the point disappears, and the place where it reappears in view. Repeat this proceeding, moving the pencil from above downwards, and in other directions. By such means, the area of the paper to which the eye is blind can be marked out. On darkly shading the area which has been marked out in the above way, it should vanish almost entirely from view, that is to say, when you look again at the cross and rest your head on the book in the same position as before.

Normally, we do not notice the blind area. This is so,

partly because the other eye fills in the gap, partly because the eyes are always on the move examining every part of the world around us. Since the optic nerve is not itself excited by light, we must seek for the sense-cells in the retina.

Place a fragment of retina, taken from the frog's eye, on a glass slide, add a drop of vinegar (1% osmic acid is best to fix the retina), and tease up the fragment with needles as finely as possible. Cover the preparation with a slip of glass, and examine with the high power of the microscope. The retina consists of several layers of cells and felt-works of cell-dendrites. You will see here and there fragments of retina with the different layers still sticking together, while numberless, tiny, round rod and cone-shaped cells may be seen scattered through the drop of vinegar. The latter are the cells of which the different layers are composed.

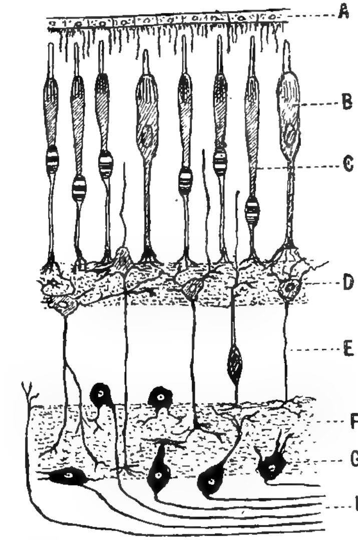


FIG. 159. Microscope, high power. Diagram of the cell layers in the retina. A. Pigment-cells. B. Cones. C. Rods. D, F. Felt-work of dendrons. E. Axon of one of the cells which lie between the rods and cones and G, the ganglion cells. H. Axons passing from ganglion cells to optic nerve. After Stöhr.

The retinal cells are arranged in this way passing from without inwards :—

1. A layer of pigment-cells lying next to the vascular choroid.

2. A layer of cells shaped like rods and cones. The rods and cones lie wrapped round by the processes of the pigment-cells and the rods contain a purple substance which is bleached by light.

3. The third layer is composed of the nuclei of the rods and cones.

4. The fourth layer is a felt-work of dendrites. The dendrites belong to the rods and cones and to the next layer of cells.

5. The fifth layer is composed of nucleated cells. These send dendrites outwards to join the last layer (4). Inwards they send axons to join the next layer (6).

6. The sixth layer is a felt-work of dendrites.

7. The seventh layer is composed of larger ganglion cells which send dendrites outwards to join the last layer (6),

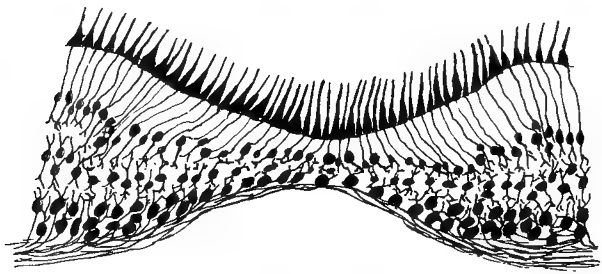


FIG. 160. Microscope, high power. Diagram showing how the layers of the retina are thinned down and the cones exposed to light in the central spot of the eye.

while inwards they send off axons which become the optic nerve-fibres.

8. The eighth layer is composed of the nerve-fibres which pass away by the optic nerve to the brain.

Now it has been proved that it is the outer layers, and probably the rods and cones, which are stimulated by light. Thus, in the frog's eye, it has been shown that the purple colour in the rods is bleached by light and restored in the dark if the layer of pigment-cells, lying next to the choroid, be left in contact with the rods and cones. Moreover, the granules of pigment creep down the processes of the cells, which lie between the rods and cones,

when the eye is exposed to light. The cones also are found to be contracted after exposure to light. All these facts suggest that rays of light produce chemical changes in the outer layers of the retina.

The yellow spot. In the centre of the back of the eye is a small oval and shallow pit somewhat yellow in colour. It is called the *yellow spot.* The layers of the retina become gradually thinned down here until in the very centre of the spot there is left only a layer of cones. If we want to see an object distinctly we look straight at it, so that the image is focussed on the yellow spot of each eye. Since the yellow spot is the seat of most acute vision, it is clear that the rod and cone layer must be the excitable part of the retina, for this layer is alone present at the bottom of the pit. The eyes are for ever in motion, turning this way and that, so that the images of each object may in turn be thrown on to the yellow spots. From the images of surrounding objects which fall on the less central parts of the retinae we gain but hazy sensations. You may search the carpet for a needle and not find it, unless its image happen to fall on the yellow spot.

It is curious to note how quickly we perceive the movement of an object placed in the outer limits of the field of vision. A leaf or paper fluttering in the wind, the movement of an animal, at once attracts our attention. The excitability of the outer parts of the retinae to moving objects is of no little importance, for we are thus warned against the attacks of men and animals.

CHAPTER XXXV

THE EYE (*continued*).

Squinting. If the eye-muscles are not properly balanced in their action, or if one muscle be paralysed, squinting results. In young children a squint is generally set up by some optical defect in the eyes, and can be corrected by the constant use of proper glasses. When we look at an object with both eyes two images are formed, one on each retina. The two images become combined into one, and we are conscious of one, not two.

With both eyes look at a pen on a table, then, by placing a finger on the upper eyelid near the nose, press one eyeball to one side. The pen will appear double.

Single vision occurs only so long as the two images are formed on those parts of the two retinae *which habitually act together*. Rays of light coming from an object lying, say, to the right of us fall on the inner side of the right retina and the outer side of the left retina. When the rays strike corresponding parts in each retina such as have been from birth onwards habitually stimulated together, we are conscious of a single image. If one eyeball be pressed aside until the image of an object falls on a part of one retina which does not naturally correspond to that part excited in the other retina, then, in such case, vision

becomes double. In looking from one object to another the eyes turn together, so that the images always fall on corresponding parts. When a person squints, his eyes no longer move harmoniously and he sees double. In such case, the person neglects one of the images, and accustoms himself to use only the straight eye. In consequence of disuse, the squinting eye atrophies. Thus a child may, owing to a squint, almost entirely lose the use of one eye. To avoid such a calamity squinting children must be taken to a doctor, so that the error of refraction in their eyes may be corrected by glasses. Very young children can, with a little trouble, be trained to wear spectacles habitually.

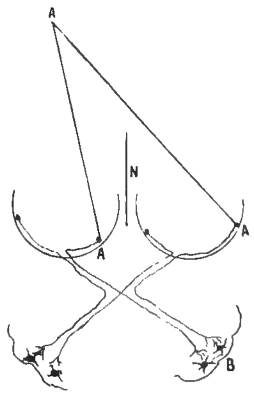


FIG. 161. Diagram of the course of the retinal nerve-fibres. Light from A strikes the outer part of the right and the inner part of the left retina. The fibres from these parts go to the right half of the brain B. N represents the nose. The spots A and A on the retinae are habitually stimulated together.

Visual judgments. Since our eyes are situated a little apart from one another, each obtains a slightly different view of any object that we may happen to look at.

On the left side of a white cup make a black inkmark. Place your head so that with the right eye alone open you can just see the mark. Now open the left eye and shut the right. The part of the cup lying beyond the inkmark will immediately become visible.

Although when both eyes be opened each retinal image differs slightly, yet at once we gain a single sensation. Not only do the two retinal images become fused into one perfect mental image, but, at the same time, we become aware of the size and solidity of the object and perceive its position in space. Now a person, who is blind

from birth and who in after years receives his sight through an operation, at first sees only coloured flat areas floating before him. He thinks all objects are in contact with his eyes. He recognises with difficulty the difference between a circle and a square. It is only by practice that he learns to associate his sensations of sight with ideas of motion and touch. During his past life he has formed ideas of objects by touching them, he has gained mental images of their position in space by moving about among them. When the new sense of sight is given to him, he feels at first confused and helpless. All his previous ideas are upset by the new strange sensations. A story is told of the case of a blind boy, who, after he received his sight, forgot on looking at them which was the dog and which the cat, but catching the cat, which he knew by feeling, he looked at her steadfastly and said, 'And so, puss, I shall know you another time.' Another child after a like experience was possessed of the idea that everything touched his eyes, and walked about most carefully, holding his hands before him to prevent things hurting his eyes by touching them.

These facts show us how we learn from infancy upwards to associate our visual sensations with those of movement and touch. The new-born child inherits the perfect apparatus, the eye, but he must learn to use it. A baby sees an object, crawls after and touches it, moves his eyes so as to look at every part of it, &c. Those who are familiar with little children notice how they stretch after the ball or other toy which is beyond their reach, and how indifferently they measure distances in running from one place to another, and so constantly fall before reaching the goal. It is through the constant association of visual mental images with those gained by touch and movement that the child learns to see things as solid, and to estimate their size and position in space.

The principle of the stereoscope. Two photographs are taken of the same object, but the camera is placed in slightly different positions so that each photograph represents the object as it is seen by one of the eyes. The stereoscope is a box divided by a central partition. The photographs are placed at the bottom of the box, one on each side of the partition. At the top of the box are placed two prisms which refract the rays in such a way that they appear to spring from a single picture. On looking through the stereoscope, a single picture of the object is seen, and this appears to stand out in relief. A pair of identical photographs seen under the stereoscope give an impression not of a solid object, but one of a flat object. If the position of any point in the two pictures should differ, the blended picture has a corresponding point in high or low relief. So great is the delicacy of this test that a good and a bad bank-note will not blend under the stereoscope into one flat surface. The stereoscope proves that there is a close connection between the difference of the retinal images on the one hand and our judgment of solidity on the other.

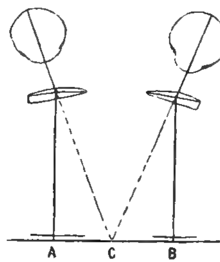


FIG. 162. Diagram of a stereoscope. Two photographs, A and B, are seen combined at C. The rays of light from A and B are refracted by the prisms into the eyes so that they appear to come from C.

In vision, we are not conscious of the existence of either retina or retinal image. We see everything *outside* the eye; nevertheless the apparent size and form of an object depends on the size, form and sharpness of its image upon the retina.

White Light and Colours.

Fit up a box with a small slit at *a*, and behind *a* place a glass prism *b*. This can be purchased from an optician for sixpence. Remove the back of the box and put in its place a sheet of tissue paper. Turn the box towards the sun so that light passes through the slit. On the tissue paper there will be seen a band of light, many-coloured like a rainbow.

The light entering by the slit cannot pass straight through to the back of the box, for it is turned aside or *refracted* by the glass prism. The white sunlight is moreover broken up or *dispersed* into red, orange, yellow, green, blue, and violet bands. The red rays are refracted least, and the violet most; the intermediate rays are arranged in the above order. This rainbow of colours is called the spectrum. If a delicate thermometer were placed just beyond the red end of the spectrum it would indicate the presence there of invisible or dark heat-rays. These rays are refracted least of all. Beyond the violet end, there fall on the screen certain rays which, although invisible to our eyes, can produce a chemical change in a photographic plate. The red end of the spectrum does not affect a photographic plate, thus red lamps are used by photographers.

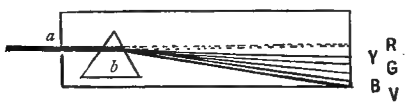


Fig. 163. Beam of sunlight entering by slit *a* broken up by a prism *b* into a band of coloured light. R. Red. Y. Yellow. G. Green. B. Blue. V. Violet.

The less rapid vibrations of the ether are invisible, but hot to the hand; as the vibrations become more and more rapid they arouse in us a sensation of red, yellow, green, blue, and finally violet light. Lastly, there are other still more rapid vibrations which can alter a photographic plate but do not stimulate any of our sense-organs.

If you turned the prism box towards a piece of glowing metal heated in a forge to a white heat, you would see the same colours. As the metal cools, the violet end of the spectrum first fades, then the other colours in their order, until red only is left. The metal is at this stage red hot. Finally the red light fades away, and the metal radiates dark heat-waves only. Suppose, while looking at the spectrum of sunlight, you placed a piece of green glass in front of the slit, most of the colours except green would disappear from the spectrum, while red glass would cut out almost all except the red light, and blue almost all except blue.

These experiments show that a green glass is green because it *absorbs* most of the colours except green, and so on with the other coloured glasses. The colours of the objects around us are due to the absorption of light. The sunlight falling upon green leaves is mostly absorbed; green and more or less blue are alone reflected to the eye. Blood reflects red rays and absorbs the rest. White paper reflects almost the whole of the light, while black reflects almost none. Blue objects absorb all except the blue rays, and reflect these.

Look at a blue flower illuminated at night by a yellow flame (produced by burning salt in a spirit lamp); it will appear quite black, for the flame is pure yellow, and there are no blue rays to be reflected. Hence dress material suitable for evening wear should be chosen by gaslight, while materials for day wear should be chosen by daylight.

Red objects absorb all except the red rays, and so on with all the coloured substances we see around us. Owing to the countless reflections of light from the irregular surfaces of the ground, from objects on the ground, and from dust in the air, we live in a bath of diffused light. If you watch the sunlight stream through a cranny in a shutter you see the course of the rays marked out by the

bright particles of dust in the air. The light reflected from these particles is diffused through the room, and so reaches the eye. If it were not for dust the passage of the rays across the room would be invisible. Whenever light is absorbed by a substance, the energy goes to increase the molecular vibration of the substance. As a ship trembles with the shock of a wave, so are the molecules of matter agitated by the impact of waves of light.

Black clothes absorb more sunlight than white garments, and thus become hotter in the sun. Therefore, in the tropics, men clothe themselves in white. The energy of the sun's light and heat is absorbed by plant life. It is used, as you will remember, for the manufacture of the complex substances, starch and proteid. Light and radiant heat may, by increasing molecular vibration, produce all kinds of chemical change. The sensitive plate of the photographer is covered with a silver compound, and this is changed by the action of light. Sunlight destroys many of the bacteria which are harmful to man, and therefore the sun should not be shut out from our rooms.

Colour mixing. Cut a disc out of cardboard and pass through the centre of it a piece of pointed wood so as to make it into a 'teetotum' top. Chalk about one-half of the disc with red chalk, and the other half chalk green. On spinning the top the colour-sensations fuse into one, and a greyish white should result. Alter the proportion of red and green until this effect is obtained. If one colour be in excess the white will be tinged with that colour.

From the inside of a Bryant and May's match-box another disc can be cut. Let it be half blue paper and half yellow wood; affix a peg, and spin this. A greyish white will be seen.

On mixing, by means of a top, any of the following pairs of colours, white light results :—

Red and bluish green.
Orange and prussian blue.
Yellow and indigo blue.
Greenish yellow and violet.
Green and purple.

The colours in each pair are therefore called *complementary*. It is clear that from the mixing of coloured lights we gain sensations which are quite different to those obtained from mixing paints. On mixing blue and yellow paint we obtain not white but green, for the mixture *reflects* green. On spinning a blue and yellow top it is otherwise, for the blue light strikes the eye before the yellow sensation is over; the two sensations then fuse and become one single sensation, namely, white.

On mixing, by means of a top, two colours which are not complementary, there results not white, but a colour diluted with more or less white. Thus purple results from a mixture either of red and violet, or of orange and blue light.

Suppose an object, while absorbing nearly all the white light, feebly reflect one colour. The colour-sensation is, in this case, mixed with the sensation of black. Browns are produced by mixing yellow light with black, greys by mixing white and black. An object may, on the other hand, reflect most of the white light and one colour in particular. The colour is then mixed with white light. The sensation of flesh-colour is produced by mixing red and white, that of sky-blue by mixing blue and white. Things we commonly call black, comparing them with strong light, are not really black.

Twist up a roll of paper and look through it at a shadow which appears black in the sunlight, it will at once seem full of light and colour Thus artists never paint even the darkest shadows black.

All coloured objects appear pale in strong sunlight, for the colours are, in this case, mixed with a greater quantity of reflected white light.

Every little bit of the retinal surface, both in and near the area of distinct vision, is sensitive to every shade of colour, but not equally sensitive. There exist no special cells or fibres sensitive to one or other colour only. If you look for a moment at the sun your eye becomes temporarily blinded and you can for a time perceive only black. Now it has been discovered that the eye, after exposure to intense red light, becomes temporarily blind to red. To do this the eye is placed behind a coloured glass and exposed to bright sunlight. The sunbeam is, by means of a lens, focussed on to the eye. On looking away from the red light to a flower garden the geraniums appear *black*, yellow flowers green, and purple flowers violet.

By changing the colour of the glass the eye can be blinded respectively for green, blue, or violet, by looking in turn at an intense green, blue, or violet light. If yellow light be looked at, the eye becomes blind to both red and green. This shows that the yellow sensation is compounded of red and green sensations. Similarly all the remaining colour-sensations are found to be compound ones.

These experiments seem to indicate the existence of four independent *primary colour-sensations*—red, green, blue, violet,—and any one of these may be temporarily abolished or fatigued by excessive stimulation. It may be supposed that each of the four[1] primary colours—red, green, blue, violet—acts on a different chemical substance in the cells of the retina. By looking at a blinding red light the store of substance excited by red is, we must suppose, temporarily exhausted, and hence the blindness to red. Similarly the substances acted on by green,

[1] Some people say three, excluding blue.

blue, or violet can be severally exhausted. On the other hand, by stimulation of the primary colour substances in various proportions, not only the sensation of white, but every colour in the spectrum can in turn be aroused. This can be proved to be so by spinning tops coloured with varying proportions of red, green, blue, and violet. There are many other ways of expressing these sensations which we have not space to discuss.

Positive after-images. On waking in the morning in a dark room strike a match and immediately blow it out; a *positive after-image* of the light persists for a moment and then gradually dies away.

If flashes of light follow each other more rapidly than ten times a second, the positive after-images of each fuse together and we become conscious of a continuous sensation. Such is the case when a catherine-wheel whizzes round and we see coloured rings of fire.

Negative after-images. Look steadfastly at a piece of white paper placed on a sheet of black paper, and then look up at a dark wall. You will now see a black spot on a whitish ground. This is a *negative after-image.*

Look at a window and then at the ceiling; the panes appear dark and the bars of the window light in the negative after-image.

The retina is fatigued by the white light, and one can suppose that the 'chemical substance' is exhausted. On looking at the ceiling, the fatigued part is less sensitive to the light of the ceiling than the unfatigued part, hence there arises a negative after-image. In a short time the sensory mechanism recovers, and the image fades away.

Look steadfastly now at a piece of red paper; a negative after-image appears on looking at the ceiling. This image will not be red, but of the complementary colour greenish blue.

By looking at red paper, the 'red substance' in the sensory mechanism is fatigued, hence, on looking at the white

ceiling, the green, blue, and violet substances are excited, while the fatigued red substance is not. The mixture of green, blue and violet, produces a sensation of greenish blue. The colours of the negative after-images produced by fatigue are as follows:—

Colour looked at.	*Complemental colour of negative after-image.*
Red	Greenish blue
Greenish blue	Red
Yellow	Indigo-blue
Indigo-blue	Yellow
Greenish yellow	Violet
Violet	Greenish yellow
Green	Purple
Purple	Green.

Contrast. Place a piece of green paper first on white and then on red; in the latter case it appears greener by *contrast.* Similarly, a piece of black paper appears blackest when placed on a white ground. Lay a small piece of grey paper on a green ground, and cover the whole with a sheet of tissue paper. The grey paper will now appear reddish. Repeat the experiment, placing the grey paper in turn on red, blue, yellow, black, and white grounds. In each case the grey, when seen through the tissue paper, takes the complementary colour.

Set up a sheet of white paper as a screen, and stick a piece of wood, e.g. a ruler, vertically in front of it. Arrange the screen and ruler in such a way in relation to the window that the latter casts a shadow on the screen. Now light a candle and move it until a second shadow is thrown on the screen. The two shadows, one due to the white daylight, the other to the yellow candle light appear not grey or black, but blue and yellow. Blow out the candle and the remaining shadow becomes greyish black. Relight the candle and the blue tinge comes back again.

While these experiments are interesting to perform, the explanation of contrast is too difficult to detain us here. By the effect of contrast the colours of objects are altered. Thus a pale face appears greenish in contrast to a red dress.

Colour-blindness. About four men out of every hundred are deficient in the power of distinguishing between certain colours. Women do not so commonly suffer from colour-blindness. Total colour-blindness has been observed in a very few men. The last mentioned perceive differences in brightness and shade, but none in colour.

Violet blindness can be temporarily produced by taking a drug called santonin. Violet and yellow then appear to be alike. Ordinary partial colour-blinds confuse red and green. One set are relatively insensitive to red and confuse a dull green with a brighter red. The other kind are very insensitive to green and match a bright green with a dull red. A man who is colour-blind cannot properly match skeins of wool. He may pick up red, pink, orange, and brown wools and match them with green of different shades. The author knows a man who cannot distinguish a green tram from one of a dark crimson colour. Such men must not be employed on ships or trains, for they are not able to distinguish the colour of signal-lamps.

Twilight Vision. The eye does not react to stimulation after resting in darkness in the same manner as in broad daylight. Red looks brighter than blue in daylight, the reverse is the case when the light is dim. There is reason to think that vision at twilight depends on a different mechanism from that which reacts at midday.

Arrange the prism as described on p. 434, using a lamp as the source of light. You will see that the orange band appears the brightest part. Now darken the room and move the lamp farther away. You will find that the brightest part is now the green.

The vision of animals such as the owl is probably like our twilight vision and they are almost blind by day. Conversely, most birds, such as the pigeon, can hardly see at all in the twilight.

CHAPTER XXXVI

SOUND.

Sound-waves. You can elicit sound from a finger-glass partly full of water by rubbing the wetted finger round its brim; the vibrations which this friction excites in the glass are rendered evident by the tremor produced in the water. Stand near a pianoforte when it is sounding, you will feel a sensible tremor in the floor of the room; any loose objects placed on the top of the piano will at the same time rattle and shake. Lay a finger on a sounding violin or bell, you will feel the same sort of tremor. The tremor ceases together with the sound.

Take a string, tie one end to a post, and pull the other tense. On twanging the string, it will make a rapid to-and-fro movement, and this will be accompanied by a musical sound. As the motion of the string becomes less ample, the sound decreases in loudness until it can no longer be heard.

Pass the blade of a table-knife up through the crack between the leaves of a table and twang the end of the blade. As you shorten the length of blade exposed, you will find that the *pitch* of the note sounded becomes higher and higher. When the blade is long, you can see the vibration; but as it is shortened the rate of vibration becomes too fast for it to be visible.

The *pitch* of a sound depends upon the number of vibrations that take place in a second of time. The *loudness* of a sound depends on the *amplitude* of the vibrations. If the knife-blade be violently twanged, the sound becomes louder. As the blade of the knife swings to and fro it

strikes the air, and the particles of air around it are set in motion. At one moment the knife swings forward (towards you) and crowds together the particles of air which lie in front, in the next moment the blade swings back, and leaves more space for these particles, while it crowds together those behind. Thus the air is alternately *condensed* and *rarified.* Each disturbance set up in the air travels outwards from the moving object in the form of a wave, just as ripples spread outwards on the face of a pond when you throw in a stone. The ripple, when it reaches the reeds in a pond, sets these in motion. Similarly, the sound-waves travelling through the air set in motion certain structures contained within the ear; thereby the nerve of hearing is excited, and the brain becomes conscious of the sound.

If the ear be placed at one end of a long beam of timber, and a person tap with his finger on the other end, the sound is distinctly conveyed. Water likewise can transmit sound. If a bell be made to ring in a glass bottle, and the air be sucked out of this by an air-pump, in proportion as the air is exhausted it is found that the sound dies away, and that it returns again as the air is readmitted. This experiment proves that the air is necessary for the conveyance of sound from the bell to the ear. Sound travels through the air at the rate of 1100 feet a second. Light travels with a far greater velocity than this, and thus we see a flash of lightning before we hear the thunder. By counting the number of seconds between the two we can roughly arrive at the distance of a storm.

Echoes are sound-waves reflected from some obstacle placed in their way, such as the wall of a house or the surface of a rock. A sound thus reflected may, by meeting another similar obstacle, be again reflected, and so the echo may be repeated many times in succession, becoming fainter, however, at each repetition till it dies

away altogether. Sound-waves are reflected in exactly the same way as light-waves, and thus they can be brought to a focus by the use of a concave reflecting surface.

Obtain a tuning-fork. Hit it, and a musical sound results. Apply it to your lip, and you can feel the vibration.

Suppose the line *T* represent the tuning-fork which is sending out waves of sound in all directions. As the tuning-fork executes one complete vibration to and fro the particle of air represented by *A* will move to *M*, from *M* back to *A*, then to *N*, and lastly from *N* back to *A*.

$$T\,\Big| \qquad N \qquad \underset{\textstyle A}{} \qquad M$$

In doing so, the particle of air will transmit the same movement to the next particle, and this to the next, and so the sound is transmitted onwards from particle to particle until it reaches the ear.

Musical sounds and noise. If the periodic vibrations of a sounding body are perfectly regular, we receive the sensation of a musical sound. This is the case with a tuning-fork. On the other hand, the periodic vibrations may be irregular, that is to say, the form and duration of the vibrations may continually change. In this case we hear a noise.

On striking the tuning-fork there occurs a series of exactly similar vibrations. These vibrations are repeated so many times a second, and a sound of a certain *pitch* is produced. If the tuning-fork be struck forcibly, the sound is louder, for the vibrations are more *ample*, and affect the ear more strongly. Any two musical sounds produced by the same number of vibrations in a second of time are said to be in *unison*. If a tuning-fork be chosen of such a length that it vibrates 100 times a second, it will,

on being struck, sound forth a note of a certain pitch. A fork that vibrates twice as fast, or 200 times a second, will sound a note of a higher pitch, namely, what is termed by musicians the octave of the first. A third fork, vibrating 300 times a second, will sound the octave of the second; a fourth, vibrating 400 times a second, the octave of the third; and so on.

Now suppose you take a series of eight forks so related that each one vibrates 2, 3, 4, 5, 6, 7, 8 times as fast as the first, and let all be sounded together. Let 2 be loudest. When all eight forks are sounding we become conscious of one blended sound of a definite pitch and *quality*. The pitch is given by the *fundamental* tone of the first fork, while the quality depends on the blending in of the other tones, which are called overtones. The quality may be altered at will by sounding one, two, or more of the forks together with the fundamental one. In the above example, the numbers of the vibrations of each tone stand in a simple numerical relation. It is only such tones that can together compose a musical sound.

In the case of a noise, such as the roar of a London street, there are countless tones, and the numbers of their vibrations bear no simple relation to each other.

Resonators. The tones that compose noises and sounds can be analysed by means of *resonators*. If you sing into the works of a piano you will hear some of the wires hum in unison. Suppose you strike a tuning-fork of the note c^2 (this is produced by 522 vibrations a second), the wire in the piano which is strung to vibrate at this rate will sound forth. Waves of sound beat 522 times a second upon the wires, and the wire which can swing at that rate is set in motion while all the others remain silent. Imagine a multitude of pianoforte wires, each

one set to vibrate at some different rate in the musical scale. If these be set before an orchestra, each wire would resonate to its own note, and by the whole number the music would be accurately hummed.

A cavity full of air will, according to its size, resonate to certain notes. Listen to a shell and you seem to hear the whisper of the sea. The cavity of the shell resonates to the slight sounds made by currents of air. In trumpets, the size of the cavity is altered by means of the keys. The mouth cavity acts as a resonator to the sounds produced by the larynx.

Timbre or quality and overtones. A violin, a piano, and a flute may sound forth the same fundamental tone, say c^1, but in each case this has a different *timbre* or *quality*. A flute gives forth comparatively simple tones, while the tones of a piano or violin are accompanied by what are termed overtones. The simplest illustration of the production of overtones is afforded by the vibrations of a violin string. If such a string be plucked, not only does it vibrate as a whole, but also in halves, quarters, eights, and so on. The sound produced by the whole string in vibration is the fundamental. Those due to its vibration in segments are the overtones or 'partials'. The overtones of the piano differ from those of the violin, and thus the quality of the sound is different. The richer the sound the more numerous are the overtones. You can sing the vowels a, e, i, o, u to the same note. It is a difference in quality that produces the vowels. Owing to the alteration in the shape of the mouth as each vowel is sung, different overtones vary in loudness. The vowels are musical sounds, while the consonants are noises.

CHAPTER XXXVII

THE EAR AND THE SENSE OF HEARING.

Waves of sound produce their effect on certain delicate hair-like processes belonging to cells in contact with which lie the branching filaments of the auditory nerve. For the sake of protection these delicate structures are deeply lodged within canals in the substance of the temporal bone. The sound-waves are conducted thither by a mechanism which is as beautiful in the simplicity of action as it is complicated in the details of structure. Roughly, the organ of hearing consists of an external ear to catch the waves of sound, an external auditory canal to convey the sound to a tympanic or drum-like membrane, and a chain of ossicles or little bones which communicate the vibrations of the tympanic membrane to a second membrane. This, in its turn, sets in motion a fluid contained within the canals of the temporal bone. When the waves of sound beat upon the tympanic membrane, this membrane vibrates in unison, the chain of ossicles communicates the same rate of vibration to the fluid in the internal ear; this stimulates the sense-cells, these the auditory nerve, and the brain hears.

The outer ear. The outer ear consists of a plate of elastic cartilage covered with skin and of a peculiar shape. The shape varies in detail in different people. The small type of ear, which has not a free dependent lobe but clings closely to the side of the head, is universally chosen to

be the most beautiful. Curiously enough, this type of ear exactly resembles that of the ourang-outang. The free lobe is a distinguishing feature of man. The outer ear continues to grow during the life of man, and is, as you may notice, much larger in old than in young people. There are some small muscles set to move the outer ear, but they are no longer used by man. Now and again, however, a man may be found who is able to move his ears. In animals, such as a cat or donkey, the large external ears are used as an ear-trumpet to gather up the sound-waves.

From the outer ear the *external auditory canal* leads inwards by a funnel-shaped opening. The canal is a little more than an inch long, is doubly curved, and is set near its mouth with fine hairs, while within, embedded in the walls, lie some small glands which secrete wax. The hairs help to prevent the entrance of insects. By means of the wax, bacteria and insects are entangled. The wax may collect in too great a quantity and, by blocking the passage, cause deafness. This can easily be removed by injecting a little warm oil and syringing with water. The external auditory canal ends at the *tympanic membrane*, and thus separates the middle from the outer ear. Children have been known in play to put a dry pea into the external auditory canal. This swells when warm and moist, and can then be extracted only with the greatest difficulty. In probing this canal, great caution must be used, for otherwise the drum may be pierced.

The middle ear. The middle ear, a small drum-like cavity full of air, is hollowed out in the substance of the temporal bone. It is separated from the external auditory canal by the tympanic membrane. On the inner wall there are two small openings, the oval window (*fenestra ovalis*) and the round window (*fenestra rotunda*). Both of these are closed by membranes. They lead to the internal ear. From the floor of the middle ear there

passes downwards a tube (the *Eustachian tube*) which opens into the pharynx. This tube is closed, except during the act of swallowing. The flaccid walls of the tube are then pulled asunder by the action of one of the swallowing muscles. By this means, the air in the middle ear is renewed. A cold in the nose sometimes spreads up the Eustachian tube. The inflammation, by producing a swelling of the mucous membrane, may then cause a blockage of the tube. So soon as the air in the middle ear is absorbed, as it is by the blood in the capillaries, the tympanic membrane becomes tense, and is unable to vibrate. This must be so, since the pressure of the atmosphere outside is no longer counterbalanced by the pressure of the air within. Many people are in this way rendered somewhat deaf by a heavy cold. The Eustachian tube can be opened and the deafness relieved by sending a blast of air up the nose at the same moment as the patient swallows. If the inflammation be severe, it may lead to the formation of matter or pus in the middle ear; in consequence, the drum becomes perforated and a discharge issues from the external auditory canal. It is of the utmost importance that such discharge should be cured. If neglected and

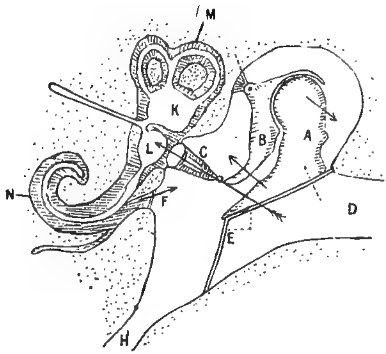


FIG. 164. Diagram of the ear. A. Hammer bone. B. Anvil bone. C. Stirrup bone projecting into oval window. D. External auditory canal. E. Tympanic membrane. F. Round window. H. Eustachian tube leading out of the middle ear or drum cavity. K. Utricle. L. Saccule. M. Semicircular canals. N. Cochlea. The shaded part of the internal ear is full of perilymph. The white part, or membranous internal ear, is full of endolymph.

allowed to become chronic, the ear may be permanently damaged thereby. Moreover, as only a thin plate of bone separates the middle ear from the brain, there is some danger of the inflammation spreading to that organ. A chain of small bones, the *auditory ossicles,* stretches across the middle ear, linking together the tympanic membrane with the fenestra ovalis or oval window. These bones are three in number, and are called from their shape the *hammer* (*malleus*), *anvil* (*incus*), and *stirrup* (*stapes*). The manner in which the bones are jointed together is shown in Fig 164. The rounded head of the malleus is jointed to a hollow in the incus. The long handle of the hammer bone is attached to the tympanic membrane. The long arm of the anvil bone is jointed to the stirrup. The plate of the stirrup is affixed to the membrane which closes the oval window. The short projections or arms of the hammer and anvil bones are attached by ligaments to the wall of the tympanum; by their means, the chain of bones is steadied in position. Two small muscles are set within the tympanum to act upon the handle of the hammer bone and upon the stirrup respectively. The function of the one is to tighten the tympanic membrane while the other probably limits the movement of the stirrup. Thus they 'stop down' the excessive vibrations due to loud sounds. When big guns are fired, the disturbance of the air is sometimes so great that the tympanic membrane of the gunner is in danger of being ruptured. The chain of ossicles acts as a system of levers; by their means, the vibrations of the drum are communicated to the membrane which closes in the oval window. Suppose a tuning-fork vibrating 100 times a second is set humming, the sound-waves enter the external auditory meatus and beat upon the tympanic membrane. This membrane vibrates 100 times a second, and the stirrup bone taps 100 times a second against the membrane of the oval window.

The internal ear. If, with a pair of strong scissors, the top and side of the skull of a dead guinea-pig or rabbit be removed, the brain may be scooped out; the part of the temporal bone which lodges the middle and internal ear is then exposed at the base of the skull. A small canal opens here, and out of this there issues the auditory nerve. Pass a wire probe into the external auditory meatus and pick away the temporal bone with the points of the scissors above the place where the end of the probe seems to lie. The roof of the middle ear may thus be taken away, and the chain of ossicles and the drum exposed. These organs in the guinea-pig are as large as in man. It is a curious fact that children are born with the middle and internal ear developed to their full size. By cutting away still more of the temporal bone, parts of the internal ear may, with care, be exposed, and you may be able to pick out a little coiled piece of hard bone shaped like a snail's shell. This is the cochlea.

FIG. 165. The bony internal ear removed from the temporal bone. *a.* Oval window. *b.* Round window. *c, d, e.* Semicircular canals. *f.* Cochlea.

The internal ear when completely shelled out from the surrounding bone has the appearance represented in the figure. It consists of a *vestibule*, out of which open three *semicircular canals* and one *cochlea*. The opening into the vestibule from the middle ear is called the *fenestra ovalis.* This, as you remember, is covered with a membrane with which the plate of the stirrup rests in contact. From the back of the vestibule the three semicircular canals project. The three are arranged so as to form a little corner seat. If you imagined yourself sitting on this seat with your back to the corner, your face would look out to the right on the right side of the head, but to the left if you sat on the left side. Each semicircular canal has a swelling at the end where it opens into the vestibule. This is called the *ampulla.* From the front of the vestibule there passes the cochlea, a tube

coiled into two and a half turns like a snail's shell. At the base of the cochlea lies the round window which would open into the middle ear were it not closed by a membrane. The bony vestibule, cochlea, and semicircular canals are together called the *osseous labyrinth.* The inner surface of the osseous labyrinth is lined with membrane; within it, there lies a fluid, the *perilymph.*

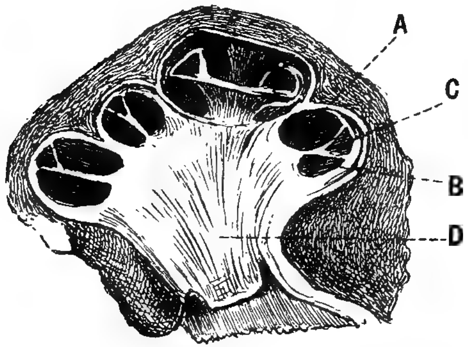


FIG. 166. The bony cochlea sawn in half. A. The scala vestibuli. B. The scala tympani. C. The membranous canal of the cochlea. D. The central pillar of the cochlea. After Kölliker.

If all the osseous labyrinth be picked off, bit by bit, there is disclosed a membranous labyrinth to which the bone forms a case. The membranous labyrinth is much smaller than the osseous labyrinth. It is held in place within the latter by bands of connective tissue and is surrounded by the perilymph. In the vestibule there lie two membranous sacs. From the larger one, the *utricle,* there open out the three *membranous semicircular canals,* each of which has one *membranous ampulla.* From the smaller sac, known as the *saccule,* a fine tube leads to the coiled *membranous canal of the cochlea.* The saccule and utricle are connected together by a very fine tube and in a roundabout fashion. Except at this one part they are entirely separated. The whole of the membranous labyrinth is filled with fluid called *endolymph,* and within lie the special sense-cells in contact with which

end the auditory nerve-fibres. In the case of the utricle, saccule, and semicircular canals the sensory epithelium is only developed in certain spots. There is one spot in each ampulla, one in the saccule, and one in the utricle. A branch of the auditory nerve goes to each spot, and the nerve-fibres end by branching round the sense-cells. The latter possess hair-like processes which project into the endolymph. The slightest movement of this fluid will affect the hair-like processes, and excite the nerve-fibrils.

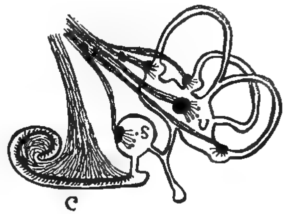


FIG. 167. Diagram of the membranous internal ear, removed from the bony internal ear and showing the branches of the auditory nerve. C. Membranous canal of cochlea. S. Saccule. U. Utricle. There is shown one nerve ending in the ampulla of each semicircular canal, one in the saccule, and one in the utricle. The nerve-endings extend throughout the length of the cochlea.

The cochlea. The bony canal of the cochlea is wound spirally round a *central pillar* of bone. This pillar is hollowed out so as to convey upwards the cochlear branch of the auditory nerve. A spiral plate of bone winds up the central pillar of the cochlea. The membranous canal of the cochlea is attached to this, and in such a way that the bony canal of the cochlea is completely divided into two spiral canals, both of which contain perilymph. The membranous canal of the cochlea filled with endolymph forms still a third spiral tube. It is small and triangular in shape. Suppose a man could climb into the vestibule through the oval window. From thence he could walk into the spiral canal which lies *above* the membranous canal of the cochlea, and when he had climbed up this to the top of the cochlea he would find a hole through which he could pass into the spiral canal which lies below the membranous canal of the cochlea. Climbing down this, he would find himself

at the bottom of the cochlea opposite the round window, and so could once more make his escape into the middle ear. Such is the path of the sound-vibrations: the stirrup bone, by tapping at the membrane of the oval window, starts waves in the perilymph which run up the cochlea and then down again to the round window. These waves beat against the membranous canal of the cochlea, and by setting the endolymph in motion, stimulate the sensory hair-cells which lie within. The membranous canal of the cochlea ends blindly at the top of the cochlea, while at the bottom, as you will remember, it is connected with the saccule. The floor of this canal is known as the *basilar membrane*.

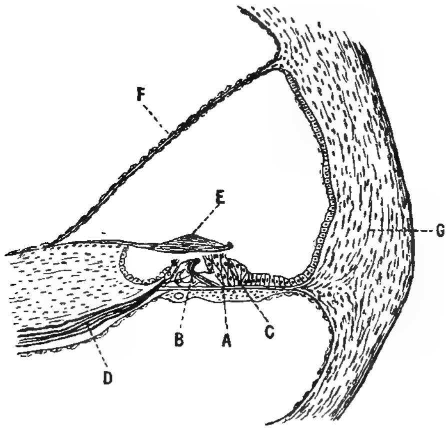


FIG. 168. Microscope, low power. Section through part of the cochlea showing the membranous canal of the cochlea. A. Basilar membrane. B. Rods of Corti. C. Hair-cells. D. Nerve-fibres. E. Membrana tectoria hanging over the hair-cells. F. Membrane separating off the membranous canal of the cochlea. G. The wall of the cochlea. After Retzius.

The organ of Corti. The basilar membrane supports the *organ of Corti*. This consists of a little tunnel formed by a great number of arched rods. It is estimated that the tunnel is formed of some 3,000 arches. Leaning against the tunnel on either side, and resting below upon the basilar membrane, are the sensory cells from which project hair-like processes. It is in contact with these

cells that the nerve-fibrils end. Since the cells are placed side by side in a continuous series along the whole of the spiral tunnel of Corti, their number is very considerable. Finally, roofing over the organ of Corti, and in close contact with the hair-like processes of the sense-cells, there hangs a soft membrane (the *membrana tectoria* or roofing membrane).

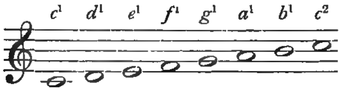
The course of the sound-waves tabulated. The course of the sound-waves is recapitulated in the following table:—

Air.
↓
Tympanic membrane.
↓
Ossicles.
↓
Membrane of oval window.
↓
Perilymph in vestibule.

↓	↓	↓	↓
Membranous utricle, containing endolymph.	Membranous saccule, containing endolymph.	Perilymph in the three bony semicircular canals.	Perilymph in upper spiral canal of cochlea.
↓	↓	↓	↓ Perilymph in lower spiral canal of cochlea. → Membranous canal of cochlea, containing endolymph.
Patch of sensory cells with hair-like processes.	Patch of sensory cells with hair-like processes.	Membranous semicircular canals, containing endolymph.	Perilymph in lower spiral canal of cochlea ↓ Membrane of round window.
↓	↓	↓	Membranous canal of cochlea ↓ Sensory cells with hair-like processes belonging to organ of Corti.
Branch of auditory nerve.	Branch of auditory nerve.	Three patches of sensory cells with hair-like processes, one in each ampulla.	↓
↓	↓	↓	Large branch of auditory nerve.
Brain.	Brain.	Branches of auditory nerve.	↓
		↓	Brain.
		Brain.	

The perception of sound. The lowest audible tone has about 16 vibrations a second, the highest about 40,000, or, according to some, 60,000 vibrations a second. To all rates of vibration above and below this range man is deaf. The extent of this range can be tested by an instrument known as Galton's whistle. The pitch is altered by a fine screw which shortens or lengthens the tube of the whistle. Men vary greatly in the power they possess of hearing high-pitched notes. Some are unable to hear even the shrill squeak of a mouse or chirrup of a sparrow. Many insects which seem to be silent, probably give forth a note which is too high in pitch to be heard by us. A cat delights in making night hideous with high-pitched squalls. This animal, it is said, hears vibrations which exceed in rapidity the limit of those audible to the ear of man. Hence perhaps the cat finds pleasure in music that is hideous to us. The ear of a good musician can detect a difference in pitch between tones of 1000 and $1000\frac{1}{5}$ vibrations a second. That is to say, if one tuning-fork vibrate 5000 times in five seconds, and another fork vibrate 5001 times in five seconds, the musician is sensitive to the difference between the two tones. So slight a difference in the stimulus produces a change in the sensation. The musician is not however sensitive to such minute differences in the case of very high and low notes, for he has not practised listening to these. The musical scale is formed of certain tones which have been selected out of the numberless audible tones. Man has chosen only such tones as give him pleasure.

In the musical scale the starting-point is the a^1 tuning-fork, which vibrates 435 times per second. The corresponding notation for the scale of pitch represented by the white keys of the piano is as follows :—



c^1 has 261 vibrations per second, c^2 has twice as many, namely, 522 vibrations per second. The interval between c^1 and c^2 is termed an *octave.* The notes in the octave bear the following relation to each other. $c^1 = 261$ vibrations per second, $d^1 = 261 \times \frac{9}{8}$, $e^1 = 261 \times \frac{5}{4}$, $f^1 = 261 \times \frac{4}{3}$, $g^1 = 261 \times \frac{3}{2}$, $a^1 = 261 \times \frac{5}{3}$, $b^1 = 261 \times \frac{15}{8}$, $c^2 = 261 \times 2$.

Sounds which bear the above relation to each are found to be suitable for musical art.

In the piano there are usually seven octaves. In each octave the notes are twice those of the corresponding notes in the octave below.

An orchestral conductor is able to discriminate the different tones that compose the complex sensations such as we receive from an orchestra. He can listen now to the violins, and now to the wind instruments or drums. Such power is acquired and made perfect by practice. It has been suggested that the organ of Corti is constructed so as to analyse sounds. If you sing into a piano, certain wires resonate and hum in response. So the fibres of the basilar membrane are supposed to respond. Each fibre, it is thought, picks out a particular note in the scale and resonates to that. The sense-cells rest upon the fibres of the basilar membrane, and the nerve-fibres lie in contact with the sense-cells; thus the vibrations of the fibres of the basilar membrane will, it is thought, influence the sense-cells, and these will in their turn stimulate the nerve-fibres. If the a^1 tuning-fork be sounded, we must suppose, according to this theory, that a particular fibre in the basilar membrane shakes, and, in consequence, a particular nerve-fibre is irritated. The nerve-fibre excites a sensation in the brain of the note in question. A peculiar disease in which

one note produces a different effect on the two ears, is in favour of this hypothesis, as we can suppose that owing to some change in size on one side, the note does not excite identical fibres in the two ears and is consequently differently perceived. Against this theory there are many facts to be set.

In birds, moreover, which have, like the nightingale, the most delicate perception of song, the cochlea is very small. There are present no rods of Corti, and the fibres of the basilar membrane are not strung regularly, and do not appear capable of resonating to different notes. It is to be noted, however, that the range even of so melodious a songster as the nightingale is very narrow, not more than two octaves. It seems more probable that all the sense-cells in the cochlea are stimulated by each and every tone.

It is conceivable that the nerve of hearing actually transmits from the sense-cells to the brain vibrations of the same frequency as the sound-waves. If this view be the true one, a tone, say, of 100 vibrations per second must cause not only the drum, the ossicles, and the perilymph, but also the sense-cells, and finally the nerve-fibres to vibrate 100 times per second, while a tone of 1000 vibrations per second will cause all these structures to vibrate 1000 times per second. According to the rate of vibration received by the grey matter of the brain we must suppose a sensation of one or other tone is aroused.

A man tries to localise sound by turning his head in one direction or another, or by moving about. While doing so, he listens whether the sound become more or less audible. A sound on the right is more audible to the right ear, and on the left to the left ear. When the head is held at rest we are often mistaken in naming the direction of a sound. We cannot tell whether it be before, behind, above, or below us. We judge the distance of a sound according to experience. For whenever we hear a sound we measure with our eyes the

distance of the sounding object. A man's voice produces a strong sensation when near to us, a weak sensation when far off. A ventriloquist uses the *inspiratory* blast of air to talk with; the voice does not therefore appear to come out of his mouth. Moreover, he imitates the sound of a voice coming from a distance, and, by means of appropriate actions, deceives us. For example, he imitates the sound of a man's voice coming from the bottom of a well, and, at the same time, pretends to listen to the voice and to look down the well. Finally, he answers the voice in his own natural tones, and the deception becomes complete.

Function of the semicircular canals. A most interesting function is assigned to the semicircular canals. If a blindfolded man be laid on a turn-table, and the table be turned round, the man feels not only the direction, but estimates the degree of movement given to his body. He can, moreover, continue to do so when the table is constructed so as to turn without the slightest noise or jar. It is clear that neither sensations of touch, sound, nor sight are excited here.

Now the six semicircular canals are arranged in pairs, and these are set in three planes at right angles to each other. Therefore whenever we move the head, the fluid in one or other pair of canals must tend to move, and the canals affected will vary with the direction of our movement in space. For example, if a dancer spins round and round on her feet, the fluid in the horizontal pair of canals will tend to move in the same direction as the body. In consequence of this movement the sense-cells situated in the ampullae must be stimulated, and the faster the movement the more will fluid press on the sense-cells. Thus, by means of these canals, we learn the direction and rate of our movement in space. The proof that this is so has been established by the following experiments :—

In crabs, prawns, and lobsters there is to be seen at the base of the small pair of antennae or feelers a little open sac. In the wall of this sac are set cells with hair-like processes, and these are supplied with nerve-fibres. Entangled in the hair-like processes are some small granules of lime or sand called *otoliths*. These structures here are exactly the same as those found in the ampullae of the semicircular canals of the higher animals. If some particles of soft iron be added to some filtered sea-water, and in this are placed some prawns, it will be found that some of the iron particles are eventually used by the prawns to form new otoliths. Now soft iron is attracted by a magnet, and on bringing a magnet near these prawns they can be made to turn their heads in one or other direction in accordance with the position of the magnet. Suppose the hair-like processes are pulled by the magnet to the right, the prawn seems to think a wave must be washing against him, and to save himself from being rolled over by this imaginary wave he turns his head to the left. Since the sea-water naturally washes in and out of the sac, the prawn feels the movement of the water and so keeps his balance. In the case of pigeons, if a hole be bored into one semicircular canal and a syringe be inserted, the pigeon will turn his head the moment the syringe is brought into play. Owing to the stimulation of the sense-cells in the canal the bird imagines it is moving, and makes a corresponding movement in the opposite direction to save itself from tumbling. If all the canals be destroyed in a bird or fish, the movements are no longer executed with steadiness or precision; the animal staggers and reels like a drunken man. Disease of these canals very rarely occurs in man; the symptoms produced thereby are giddiness, noises in the head, and a reeling gait.

CHAPTER XXXVIII

THE LARYNX, VOICE, AND SPEECH.

At the top of the trachea lies the larynx. It opens into the pharynx above and the trachea below. The opening into the larynx lies at the root of the tongue; this is known as the glottis, and over it there projects a valve-like flap, the epiglottis. The gullet lies at the back of the larynx.

Dissection of the sheep's larynx. Purchase from the butcher a sheep's tongue with the larynx, windpipe, and gullet attached. The gullet will be adherent behind, and the larynx will be clothed in front with thin bands of muscle. These muscles pass from the most prominent cartilage of the larynx, the thyroid or Adam's apple, upwards to the *hyoid* bone, and downwards to the sternum. The hyoid is a small bony arch lying embedded in the muscles below the root of the tongue. It is slung to the skull by muscle and ligament, and forms a point of attachment for muscles which pass upwards to the tongue and downwards to the thyroid cartilage and sternum. Slit open the gullet and expose the glottis. You will see in the middle of the glottis a slit or chink, running from front to back. The edges of this slit are called the *vocal cords.* Each cord is set like the reed in a whistle or organ-pipe, and its edge, like that of a reed, is sharp cut. By means of the laryngeal muscles the cords can be tightened or relaxed, and thus different notes can be sounded when a blast of air is driven through the larynx.

Press down the top of the epiglottis so as to shut off the opening into the larynx. The epiglottis affords a smooth surface over

which the food slides into the oesophagus. Notice the smooth, glistening mucous membrane forming the inner lining of the gullet and larynx. Clean off the muscles and fat from the front and sides of the larynx and expose its cartilaginous framework. At the top of the trachea lies the *cricoid cartilage.* This is shaped like a signet ring, the narrow part of the ring being in front and the broad part behind. It is this broad expansion that forms the firm posterior wall of the larynx. On the top of the expanded portion of the cricoid and at the back of the glottis, there rest the two little *arytenoid cartilages.* The arytenoids, somewhat pyramidal in shape, are each attached to the cricoid cartilage by a pivot joint. The vocal cords arise from the thyroid cartilage in front, and, diverging as they go, are attached behind, one to each arytenoid cartilage. On looking into the glottis the arytenoids appear like two little cushions set on either side of the chink and at its hinder part. The *thyroid cartilage* is a broad V-shaped cartilage. Flattened at the sides, and forming a prominent ridge in front of the neck, this cartilage leaves a wide gap behind. Thus while the thyroid forms the front and sides of the larynx, the cricoid and arytenoid cartilages form the back wall.

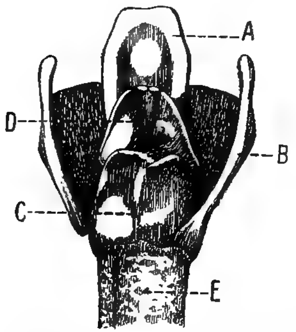


FIG. 169. The cartilages of the larynx as seen from behind. A. Epiglottis. B. Thyroid. C. Cricoid. D. Arytenoid. E. Trachea.

Between the cricoid and the thyroid cartilages in front there is a small gap which is filled up by membrane only. The sides of the thyroid cartilage are prolonged above and below into horns. The upper pair of horns is bound to the arch of the hyoid bone, the lower pair is articulated by a pivot joint to the outside of the cricoid cartilage. To study the object of this joint, carry out the following experiment. Fix the thyroid cartilage with the fingers and push the front of the cricoid upwards; this movement will cause the broad expanded part of the cricoid to be tilted backwards. Since the arytenoid cartilages resting on

the top of the cricoid will likewise be carried backwards, this movement causes the vocal cords to be stretched and tightened.

Now on each side there can be seen the *crico-thyroid* muscle, the fibres of which run from the thyroid to the cricoid cartilage; the function of this muscle is to tilt the cricoid and tighten the vocal cords just as you did in the above experiment.

In addition, there are small muscles that pass from the cricoid to the arytenoid cartilages. These act in such a way as to cause the arytenoid cartilages to swivel round upon their pivot joints. By this means, the vocal cords are brought parallel and near together, or set divergent and far apart, and the chink of the glottis is thereby narrowed or widened. The two arytenoid cartilages are likewise strapped together by little muscles. The arytenoid cartilages are brought closer together when these contract, and the approximation of the vocal cords is thus aided. Lastly, on either side, there runs a muscle embedded in the substance of the fold of membrane which forms either vocal cord. The action of this muscle is to approximate the arytenoid cartilages to the thyroid and so slacken the cords.

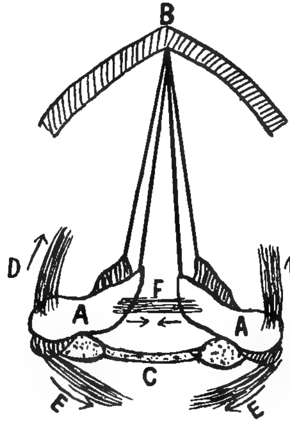


FIG. 170. Diagram showing the action of some of the muscles of the larynx. A. Arytenoid cartilages. B. Front part of thyroid cartilage. C. Top of cricoid cartilage on which arytenoids are pivoted. Vocal cords run from A to B. The muscles D pull the arytenoids into the unshaded position and so bring the cords near together. The muscles E pull the arytenoids into the shaded position and so separate the cords. The muscles F bring the arytenoids nearer together and so approximate the cords.

Some of the muscular fibres arising from the thyroid do not run the whole length of the cords, but are inserted at different parts of the same. By means of these the cords can be slackened either in part or in the whole of their length.

The vocal cords, superficially covered with mucous membrane, are also strengthened within by straight elastic fibres. These

fibres run from the thyroid in front to the arytenoid cartilage behind.

The vocal cords in man. The glottis can be observed in a living man by means of a little mirror set on a long handle and passed to the back of the throat. A strong light is thrown from a lamp on to this mirror by means of another and slightly concave mirror which is fixed to the forehead of the observer and is pierced with a hole for his eye. Through this, the observer can see in the small mirror the reflected image of the glottis.

The chink of the glottis appears V-shaped when the vocal cords are at rest and no sound is made. So soon as the man speaks, however, the arytenoid cartilages are drawn together, the vocal cords become parallel, the glottis a narrow slit.

The production of voice. By means of the crico-thyroid and thyro-arytenoid muscles, the tension of the vocal cords can be varied at will. On the degree of tension depends the pitch of the note sounded. By pulling a string now taut and now slack, and twanging it each time, you can produce notes of a different pitch.

Place the tip of the finger in the space which can be felt between the thyroid and cricoid cartilage in front of the neck. If you now sound a low note, and then suddenly change to a high one, you will feel that this space diminishes as the front of the thyroid moves downwards and forwards. The figure shows that the vocal cords are by this means put on the stretch. The whole larynx is, at the same time, drawn upwards.

Men have deeper notes than women or boys because in them the larynx is larger and the vocal cords longer. As the larynx enlarges at puberty, the voice of a boy cracks. The shorter the cord the more rapidly it vibrates, and the higher the pitch. The falsetto voice in man is probably produced by the action of certain fibres of the

thyro-arytenoid muscles. A certain length of each cord is slackened and the rest thrown into tension. A violinist in the same way varies the pitch of a note by 'stopping' the string of his violin at varying distances.

The range of a voice depends upon the different degrees of tension which can be given to the vocal cords. The power of 'stopping' just mentioned also increases the range of pitch.

The quality of a voice depends on the smoothness, elasticity, and thickness of the cords. More than this, the form of the air-passages, larynx, pharynx, and mouth is of great importance in determining quality, for these act as resonators or resounding chambers, and, like the box of a fiddle, intensify the sound and modify the overtones which accompany the fundamental tone. If it were not for these resonating chambers the voice would be feeble. By means of a speaking-trumpet the sound can be still further intensified. By altering the shape of the mouth the quality of the voice can be changed.

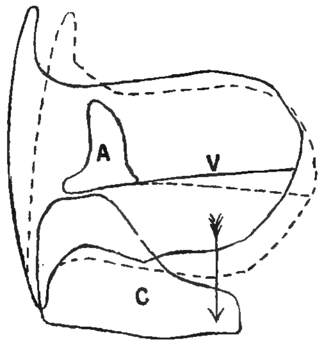


FIG. 171. Diagram showing the action of the crico-thyroid muscle. A. Arytenoid cartilage. C. Cricoid. V. Vocal cords.

The muscular movements required to produce song are most complicated, and these can only be carried out with perfect accuracy after continual practice and years of training. The exact degree of tension must be given to the vocal cords to produce the required pitch, and, at the same time, the quality must be determined by the muscles of the mouth and throat, and all these movements the singer must learn to execute not only with precision

but with the greatest rapidity. To be a great singer a man must be born, not only with a larynx suitable for song, but with an ear tuned to the delicate perception of musical notes. The range of voice seldom exceeds two and a half octaves. The numerous muscles engaged in the production of voice are supplied with nerves which issue from the grey matter in the spinal bulb; these are under the control of the grey matter situated in the lower part of the frontal lobe of the cerebrum. The brain orders the muscles to

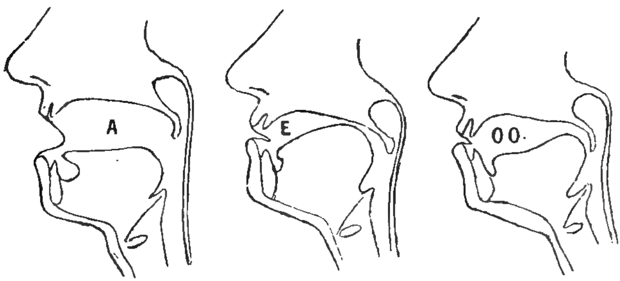


FIG. 172. The shape of the mouth in sounding different vowels.

act, the voice sounds, the ear hears, the sensory nerves tell the brain in what way the muscles engaged in producing the sound are acting.

Speech, vowels, and consonants. Speech and voice must be distinguished from each other. A whisper is speech produced without voice, for the vocal cords do not vibrate. In whispering, the slight sound produced by the air passing through the air-passages is modified into speech by movements of the tongue and lips. In ordinary talk, speech is produced by modulating the voice by means of the tongue and lips, whereby the form of the mouth and pharynx is altered. Vowel-sounds can be sung to one and the same note produced in the larynx, if this be altered in quality by changing the shape of the resonating chamber, viz. the mouth.

Pronounce the pure vowel-sounds *E* as in *he*, *A* as in *ay*, *A* as in *ah*, *O* as in *oh*, *Oo* as in *coo*, and notice that they are produced by varying the form of the cavity and the shape of the opening of the mouth. The consonants are produced by closing, more or less, certain doors on the outgoing blast. If the door be partly closed and the air rush through with a hiss, the result is an 'aspirate.' Aspirates—*F*, *V*, *W* (lips), *S*, *Z*, *L*, *Sch*, *Th* (tongue and hard palate), *J*, *Ch* (tongue and soft palate), *H* (vocal cords). The consonant *H* is pronounced by increasing the expiratory force with which the vowel is spoken. The vowel is, as it were, coughed out. If the door be partly closed and its margins thrown into vibration, there results a 'vibrative,' e.g. *R* (tongue and hard palate).

The 'resonants' *M* and *N* are formed by sending the current of air through the nose; in the case of *M*, the lips are closed, while to pronounce *N* the tongue is applied to the palate. The remaining consonants are 'explosive.' In the case of *B*, *P*, *T*, *D*, *K*, and *G* hard, the mouth is closed and then suddenly burst open. To pronounce *B* and *P* the lips are shut; in *T* and *D* the tongue is applied to the teeth or front part of the palate respectively; while in *K* and *G* hard, the middle or back of the tongue is forced against the back of the palate.

Children born deaf are also dumb, for they do not hear words and so do not learn to speak. If a dumb child be trained to watch the shape and movements of the teacher's mouth when the latter is naming an object, he may learn to imitate these and so come to speak. A child is in danger of becoming dumb who, owing to inflammation of both ears, becomes deaf before he is six years old. He tends to forget the language which he has learnt.

Stammering is due to a lack of control over the movements of the speech-muscles.

CHAPTER XXXIX

DEATH.

We have now reached the closing pages in the study of life. From the preceding chapters you will have learnt something of the wonderful structures, something of the manifold functions, which, taken together, compose a living man. While the astronomer stands astounded by the infinite greatness of space and time, the student of physiology is amazed at the mysteries of the infinitely little. He strives to unravel the ever-changing structure of the protoplasmic molecules, and seeks to know how and why they are thrilled by waves of energy and dance the dance of life. Much we have learnt, and yet the greater mysteries of life remain unsolved. Think of the egg-cells of a silkworm moth, and those of a frog, and a bird. Chemical tests and the microscope show to us scarcely any differences in these tiny specks of protoplasm, and yet, when they develop, how different is their destiny. We know nothing of the forces that control the growth of ova; we cannot tell why the child inherits the form of its parents, nor why the parents die, and only their egg-cells are set aside to continue the chain of life. Think of the growth of the body of a chicken from the egg; of how the cells, as they multiply, become marshalled into tissues and organs; of the nervous system, its intricate structure and marvellous development; and the mystery of the brain of man musing upon the nature of itself. Finally, there is ever before us the great unsolved mystery of death.

Local death is continually going on in our bodies, but of this we are not conscious. The worn-out cells of the blood, of the epidermis, and of the mucous membranes are continually cast off and replaced by others which, as continually, come into existence. The body is for ever changing; growth is replaced by maturity, and maturity by decay. In the young, the brain grows, and fresh tracts and pathways of association are laid down as memories accumulate and habits of thought and action are formed. In the old, on the other hand, the brain steadily diminishes in weight, and the mind slowly decays and falls into dotage.

Moulded by the forces around us, we are to-day different beings from what we were ten years ago. The spring is wound up at birth, and the wheels of life run for an allotted spàn. Finally, the inborn power of repair is spent. The mechanism, if not at some earlier period rudely broken, is stopped at last by the clogging power of decay.

Local death produced by injury may be extensive and yet be repaired. Broken bones unite and wounds scar over. Nevertheless a man cannot, by the process of repair, regain a lost limb or organ. It is otherwise in the case of lower forms of life, such as the hydra. This animal may be divided in two, and each bit will develop into a new and complete animal. The surgeon, by his art, can aid the natural process of repair. He may cover the raw surface of a wound by transplanting upon it little bits or grafts of skin. Fragments of bone may be taken by him from animals, and used to fill up the gap left by the removal of diseased bone. He may stitch together severed nerves, and, by thus enabling the axons to grow down the sheaths of the degenerated fibres, endow the paralysed parts with nervous energy. The surgeon may likewise unite the ends of a coil of intestine severed by some

penetrating wound of the abdomen; he may, by tying up wounded arteries, prevent a fatal loss of blood; and even operate with success upon the brain, and remove a blood-clot or fragments of bone, which, as the result of a broken head, may be pressing upon that organ. Surgery, since Lister's discovery of the method of preventing the entry of bacteria into wounds, has made enormous advances, and there is no cavity of the body which the surgeon dare not now explore. But the art has its limits: the surgeon can only aid natural repair, or remove diseased parts and parasitic growths; he cannot prevent old age and death. Recently the physiologist has succeeded in transplanting a kidney and even a limb from one dog to another, joining blood-vessel to blood-vessel. It is conceivable then that a kidney might be taken from a man killed by accident and grafted on to a man whose kidneys were diseased.

General death occurs so soon as the heart has finally ceased to beat. When the circulation fails, consciousness at once vanishes; the tissues, on the other hand, continue to live, for some little time, after the spirit of life has fled. Thus in executed criminals, the cells in the trachea continue for a time to lash their cilia, the bowels writhe, and the skeletal muscles contract when stimulated. Life depends upon the mutual give and take of the organs of digestion, absorption, respiration, circulation, and excretion, and upon the control of all these by the nervous system. If any of the organs fail, death of the remainder must eventually follow. But as the arrest of the circulation acts upon the other functions directly and immediately, death is finally brought about in every case by the cessation of the heart-beat. We distinguish natural death, brought about by old age or disease, from violent death caused by starvation, exposure to cold, poisons, or injuries.

It is the aim of man to attain to a peaceful and natural

death from old age, and, by the study of the causes of disease and by the advance of social progress, to eliminate more and more all other forms of death.

Advance of social progress and the decline of war steadily lessen the number of violent deaths. Deaths produced by infective diseases can be limited by better sanitation, and can be combated by extending our knowledge of bacteriology. Finally, deaths from premature degeneration of the organs can be diminished by improved modes of life, for they largely owe their origin to overstrain, alcoholism, and wrong feeding, and excesses of various kinds. The most important factor in determining a long life is heredity. Long-lived parents as a rule produce long-lived children.

The process of dying, we may be assured, is not in itself painful. 'Men feare Death,' says Bacon, 'as Children feare to goe in the darke. And as that Natural Feare in Children is increased with Tales, so is the other.' A famous physician on his death-bed wished he could be at the trouble to tell his friends how pleasant a thing it was to die. While the body and mind are to a certain extent still vigorous, suffering may be endured from the ravages of disease, but as the end draws near, the nutrition of the brain is so enfeebled that all poignant feeling is rendered impossible. The throes and convulsions that occur in a violent death from suffocation do not denote agony, for consciousness is lost in a few seconds of time, so soon indeed as the brain is deprived of oxygenated blood. Convulsions occur owing to the excitation of the lower nerve-centres by the venous blood. Men, when recovered from drowning, describe how pleasant dreams and fantasies coursed through their minds; they have no memory of any pain. The condition of the mind, when death approaches, is akin to that of dreaming. Men on their death-beds often utter words

and perform actions which signify that they are enacting some familiar scene. Thus a lawyer died uttering the words, 'Gentlemen of the jury, you will find'; a doctor, in his last moments, gave directions to an imaginary patient, and a preacher gave expression to eloquent fragments of sermons. Picking at the bed-clothes and catching at the air are actions which represent the phantasies passing through the minds of the dying. Some childish memory may frequently be the last to persist. Shakspere thus describes with a masterly hand the death-bed scene of Falstaff: 'I saw him fumble with the sheets and play with flowers and smile upon his fingers' ends. I knew there was but one way; for his nose was as sharp as a pen, and a' babbled of green fields.'

So soon as death is complete bacteria invade the body, decomposition begins, and little by little the complex molecules of the tissues are broken to pieces and dissipated in the form of carbon dioxide, ammonia, water, and mineral salts. Some of these molecules may eventually be built up again into vegetable life, and thence once more enter into the structure of animals. We may let our fancy speculate upon the wanderings of these molecules, and, as Huxley suggests, imagine that some of them which at one time entered into the structure of the 'busy brain of Julius Caesar may now enter into the composition of Caesar the negro in Alabama, and of Caesar the house-dog in the English homestead,' or think with Shakspere that,

'Imperial Caesar, dead and turned to clay,
Might stop a hole to keep the cold away.'

APPENDIX I

To aid the private student and teacher a list of the simple apparatus required for the practical work is appended. The approximate cost of the same is also indicated.

			s.	*d.*
Hydrometer scaled 1000–1100			1	5
Metre measure-rule, boxwood (Gallenkamp)				6
Balance weighing to 50 grammes „			1	0
Two tins of litmus paper, blue and red (Gallenkamp)				4
Measure-glass, 100 c.c.			1	3
Thermometer scaled to 212° F.			1	3
Porcelain evaporating dish		for evaporating urine, &c.		2
Bunsen gas-burner				11
Tripod stand				8
Piece of wire gauze				2
Test-tubes, a dozen				4
Glass filter funnel				3
Glass flasks, 6 oz. each				3
Glass tubing, $\frac{4}{16}$ inch, per lb.		for circulation experiments, &c.	1	0
„ „ $\frac{1}{2}$ „ „			1	0
Enema syringe			2	6
Rubber tubing, $\frac{3}{16}$ inch, per yard				6
Biconvex lens				6
Prism				6
Watch-glasses, per doz.				8
Microscope slides „				3
„ cover-slips, ½ oz.			1	6
Fuming nitric acid	1 oz.	each about 3*d.*		
Sulphuric acid, 25 %	„			
Hydrochloric acid	„			
Ammonia	„			

Copper sulphate solution		1 oz.	each about 3*d.*
Iodine . .	"	"	
Caustic potash	"	20 % "	
Sodium carbonate	"	1 % "	
Silver nitrate	"	1% "	
Barium chloride	"	"	

An efficient microscope, such as Leitz's, can be obtained for about £4 5*s*.

A skull, vertebral column, and the bones of one arm and one leg can be bought for about £2.

Such apparatus can be obtained from Gallenkamp & Co., 19 Sun Street, E. C.; Baird & Tatlock, Cross Street, Hatton Garden, E.C. ; or any other dealer in chemical apparatus.

APPENDIX II

A SIMPLE METHOD OF CUTTING SECTIONS OF THE ORGANS, TAKEN FROM A FRESHLY KILLED ANIMAL. FOR MICROSCOPICAL EXAMINATION.

OBTAIN some bullock's liver. Boil it and then cut it into pieces 1 inch long and $\frac{1}{2}$ inch broad. Keep these in dilute methylated spirit (one part spirit to two of water) in a well-corked jar.

1. Cut a piece not bigger than $\frac{1}{4}$ inch from the organ.
2. Harden it by placing it in methylated spirit for a day or two.
3. Wash the piece in water until it sinks.
4. Make a slit in a piece of the liver and insert the bit of organ in this, and holding it there by compressing the liver between the finger and thumb, cut the thinnest possible sections, through the liver and organ, with a very sharp razor. The razor should be wet with water. The piece of liver makes a convenient holder and cuts very easily.
5. Float the sections off the razor into a watch-glass full of water.
6. Stain the sections by adding a few drops of *carmalum* to the water.

7. When stained, lift the sections of the organ into clean water. The sections can be lifted on the point of a needle stuck in a penholder.

8. Next lift the sections into a watch-glass full of methylated spirit. This removes the water.

9. After a minute or two transfer them to a watch-glass containing oil of cloves. The sections should, if free from water, now become perfectly transparent.

10. Finally float a section on to a cover-glass, manipulating it in the oil of cloves with the help of a needle.

11. Place a drop of Canada balsam solution on a slide, and lifting up the cover-slip with the section upon it, drain off the oil, and then gently lower the cover-slip, with the section downwards, on to the balsam. The preparation will now be a permanent one.

In place of this somewhat lengthy process the sections, after they have been stained, can be mounted on a slide in a drop of glycerine and water; the edges of the cover-slip must then be painted with gold size in order to ensure their preservation.

Fragments of the organs can be unravelled, on a glass slide, with the help of needles, after maceration for a day or two in weak alcohol (1 part to 3 of water), or after treatment for a short time with strong potash solution, 35 %.

The stain carmalum is composed of—

Carminic acid, 1 gramme.
Ammonia alum, 10 grammes.
Distilled water, 200 cubic centimetres.

A small piece of thymol is added to prevent the growth of moulds.

The carmalum, clove-oil, and Canada balsam solution can be obtained from Messrs. Baird and Tatlock, Cross Street, Hatton Garden, E.C.

Microscopical preparations of the tissues are lent out on hire by Messrs. Baker, Opticians, High Holborn, W.C.

For the details of microscopical work the reader is referred to Schäfer's *Essentials of Histology*. For the advanced study of physiology, read Howell's *Physiology* (Saunders), and the Practical Physiology published by Arnold.

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